

DOT POINT

VISIT...

IB PHYSICS OPTIONS



hargava



S

Science Press

© Science Press 2010
First published 2010

Science Press
Private Bag 7023 Marrickville NSW 1475 Australia
Tel: +61 2 9516 1122 Fax: +61 2 9550 1915
sales@sciencepress.com.au
www.sciencepress.com.au

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of Science Press. ABN 98 000 073 861

Copyright statements © IBO 2007 refer to the syllabus guide published by the International Baccalaureate Organization.

Thanks to the International Baccalaureate Organization for permission to reproduce its intellectual property.

This material has been developed independently by the publisher and the content is in no way connected with or endorsed by the International Baccalaureate Organization.

Contents

Introduction	v
Command Terms and Verbs to Watch	vi

Dot Points

Sight and Wave Phenomena	vii	Communications	xvii
Quantum Physics and Nuclear Physics	ix	Electromagnetic Waves	xix
Digital Technology	xi	Relativity	xxi
Relativity and Particle Physics	xiii	Medical Physics	xxiii
Astrophysics	xv	Particle Physics	xxv

Questions

Sight and Wave Phenomena	1	Communications	241
Quantum Physics and Nuclear Physics	49	Electromagnetic Waves	293
Digital Technology	97	Relativity	351
Relativity and Particle Physics	141	Medical Physics	401
Astrophysics	189	Particle Physics	453

Answers

Sight and Wave Phenomena	503	Communications	571
Quantum Physics and Nuclear Physics	517	Electromagnetic Waves	589
Digital Technology	527	Relativity	611
Relativity and Particle Physics	541	Medical Physics	625
Astrophysics	557	Particle Physics	641

Appendices

Data Sheet	659
Periodic Table	660
Index	661

The image shows the top portion of a notebook page. At the very top, there is a horizontal strip with a dark, grainy texture, resembling a photograph of a starry night sky or a close-up of a planet's surface. Below this strip, the word "Notes" is printed in a simple, black font. The majority of the page below "Notes" consists of numerous horizontal dotted lines, providing space for writing. In the bottom right corner of the page, the words "Science Press" are printed. Along the bottom edge of the page, there is a dark grey bar containing three elements from left to right: the word "Contents", the Roman numeral "iv", and the phrase "Dot Point IB Physics Options".

Introduction

What the book includes

This book provides questions and answers for each dot point in the IB Physics Options syllabus from the International Baccalaureate Diploma Programme for Physics:

- Sight and Wave Phenomena
- Quantum Physics and Nuclear Physics
- Digital Technology
- Relativity and Particle Physics
- Astrophysics
- Communications
- Electromagnetic Waves
- Relativity
- Medical Physics
- Particle Physics

Format of the book

The book has been formatted in the following way:

1.1 Subtopic from syllabus.

1.1.1 Assessment statement from syllabus.

1.1.1.1 First question for this assessment statement.

1.1.1.2 Second question for this assessment statement.

The number of lines provided for each answer gives an indication of how many marks the question might be worth in an examination. As a rough rule, every two lines of answer might be worth 1 mark.

How to use the book

Completing all questions will provide you with a summary of all the work you need to know from the syllabus. You may have done work in addition to this with your teacher as extension work. Obviously this is not covered, but you may need to know this additional work for your school exams.

When working through the questions, write the answers you have to look up in a different colour to those you know without having to research the work. This will provide you with a quick reference for work needing further revision.

Command Terms and Verbs to Watch

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Interpret data to reach conclusions.

annotate Add brief notes to a diagram or graph.

apply Use an idea, equation, principle, theory or law in a new situation.

assess Make a judgement of value, quality, outcomes, results or size.

calculate Find a numerical answer showing the relevant stages in the working (unless instructed not to do so).

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

comment Give a judgement based on a given statement or result of a calculation.

compare Give an account of similarities and differences between two (or more) items, referring to both (all) of them throughout.

construct Represent or develop in graphical form.

contrast Show how things are different or opposite.

deduce Reach a conclusion from the information given.

define Give the precise meaning of a word, phrase or physical quantity.

demonstrate Show by example.

derive Manipulate a mathematical relationship(s) to give a new equation or relationship.

describe Give a detailed account.

design Produce a plan, simulation or model.

determine Find the only possible answer.

discuss Give an account including, where possible, a range of arguments for and against the relative importance of various factors, or comparisons of alternative hypotheses.

distinguish Give differences between two or more different items.

draw Represent by means of pencil lines.

estimate Find an approximate value for an unknown quantity.

evaluate Assess the implications and limitations.

examine Inquire into.

explain Give a detailed account of causes, reasons or mechanisms.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

identify Find an answer from a given number of possibilities.

justify Support an argument or conclusion.

label Add labels to a diagram.

list Give a sequence of names or other brief answers with no explanation.

measure Find a value for a quantity.

outline Give a brief account or summary.

predict Give an expected result.

propose Put forward a point of view, idea, argument, suggestion etc for consideration or action.

recall Present remembered ideas, facts or experiences.

show Give the steps in a calculation or derivation.

sketch Represent by means of a graph showing a line and labelled but unscaled axes but with important features (for example, intercept) clearly indicated.

solve Obtain an answer using algebraic and/or numerical methods.

state Give a specific name, value or other brief answer without explanation or calculation.

suggest Propose a hypothesis or other possible answer.

summarise Express concisely the relevant details.

synthesise Put together various elements to make a whole.

Sight and Wave Phenomena

Dot Point	Page	Dot Point	Page
A1 The eye and sight	3	A5 Resolution	37
A.1.1 Basic structure of the human eye.	3	A.5.1 Sketching the angle of diffraction versus intensity of light from two point sources.	37
A.1.2 Depth of vision and accommodation.	4	A.5.2 Rayleigh criterion.	38
A.1.3 Rods and cones.	6	A.5.3 Resolving power and technology.	38
A.1.4 Photopic and scotopic vision.	7	A.5.4 Questions on resolution.	39
A.1.5 Colour mixing of light by addition and subtraction.	10	A6 Polarisation	41
A.1.6 Effect of light, dark and colour on perception of objects.	12	A.6.1 Polarised light.	41
Wave Phenomena: A2-A6 are identical to 11.1-11.5.		A.6.2 Polarisation by reflection.	41
A2 Standing (stationary) waves	15	A.6.3 Brewster's law.	41
A.2.1 Nature of standing waves.	15	A.6.4 Polarisers and analysers.	42
A.2.2 Formation of standing waves.	15	A.6.5 Malus' law.	43
A.2.3 Standing waves in strings and pipes.	16	A.6.6 Optically active substances.	43
A.2.4 Comparing standard waves and travelling waves.	19	A.6.7 Using polarisation to find concentration of certain solutions.	45
A.2.5 Questions on standing waves.	20	A.6.8 Using polarisation in stress analysis.	45
A3 Doppler effect	25	A.6.9 Action of liquid-crystal displays (LCDs).	45
A.3.1 Doppler effect.	25	A.6.10 Questions on polarisation of light.	48
A.3.2 Explaining the Doppler effect.	25	Answers to Sight and Wave Phenomena	503
A.3.3 Doppler equations for sound.	27		
A.3.4 Questions on the Doppler effect for sound.	27		
A.3.5 Questions on the Doppler effect for electromagnetic waves.	29		
A.3.6 Using the Doppler effect to measure speed.	30		
A4 Diffraction	33		
Diffraction at a single slit			
A.4.1 Sketching the angle of diffraction versus intensity of light.	33		
A.4.2 Deriving the diffraction formula: $\theta = \frac{\lambda}{b}$	34		
A.4.3 Questions on single-slit diffraction.	34		

This image shows a full page of white paper with horizontal dotted lines, resembling notebook paper. The lines are evenly spaced and run across the width of the page. There is no handwriting or other markings on the paper.

Quantum Physics and Nuclear Physics

Dot Point	Page	Dot Point	Page
B1-B2 are identical to 13.1-13.2.		B2 Nuclear physics	81
B1 Quantum physics	51	B.2.1 Estimating radii of nuclei.	81
Quantum nature of radiation		B.2.2 Measuring masses of nuclei.	83
B.1.1 Photoelectric effect.	51	B.2.3 Evidence for nuclear energy levels.	89
B.1.2 Explaining the photoelectric effect using the Einstein model and the concept of a photon.	53	Radioactive decay	
B.1.3 Millikan's experimental verification of the Einstein model.	55	B.2.4 β^+ decay and neutrinos.	90
B.1.4 Questions on the photoelectric effect.	58	B.2.5 Radioactive decay law and decay constant.	90
Wave nature of matter		B.2.6 Decay constant and half-life.	90
B.1.5 De Broglie hypothesis and matter waves.	66	B.2.7 Measuring the half-life of an isotope.	91
B.1.6 Davisson and Germer's experimental verification of the de Broglie hypothesis.	66	B.2.8 Questions on radioactive half-life.	94
B.1.7 Questions on matter waves.	66	Answers to Quantum Physics and Nuclear Physics	517
Atomic spectra and atomic energy states			
B.1.8 Laboratory procedures for producing and observing atomic spectra.	70		
B.1.9 Atomic spectra as evidence for quantisation of energy in atoms.	70		
B.1.10 Questions on wavelengths for spectral lines and energy level differences.	73		
B.1.11 Origin of atomic energy levels and the 'electron in a box' model.	77		
B.1.12 Schrödinger model of the hydrogen atom.	77		
B.1.13 Heisenberg uncertainty principle.	79		

This image shows a full page of a document template. It consists of approximately 30 evenly spaced horizontal dotted lines across the entire width of the page, providing a guide for handwriting or typing. There are no margins, text, or other markings present.

Digital Technology

Dot Point	Page	Dot Point	Page
C1-C2 are identical to 14.1-14.2.		C3-C4 are identical to F5-F6.	
C1 Analog and digital signals	99	C3 Electronics	125
C.1.1 Questions on conversion between binary and decimal numbers.	99	C.3.1 Properties of an ideal operational amplifier (op-amp).	125
C.1.2 Information storage in analog and digital forms.	100	C.3.2 Drawing circuit diagrams for inverting and non-inverting amplifiers.	126
C.1.3 Using interference of light to recover information from a CD.	103	C.3.3 Deriving an expression for the gain of inverting and non-inverting amplifiers.	129
C.1.4 Questions on depth of pits on a CD.	103	C.3.4 Using an operational amplifier circuit as a comparator.	131
C.1.5 Questions on storage capacity of CDs and DVDs.	105	C.3.5 Using a Schmitt trigger to reshape digital pulses.	131
C.1.6 Advantages of digital form for storage of information.	109	C.3.6 Questions on circuits incorporating operational amplifiers.	134
C.1.7 Implications for society of ever-increasing capability of data storage.	109		
C2 Data capture; digital imaging using charge-coupled devices (CCDs)	111	C4 The mobile phone system	139
C.2.1 Capacitance.	111	C.4.1 Areas divided into cells.	139
C.2.2 Structure of a charge-coupled device.	112	C.4.2 Role of cellular exchange and public switched telephone network (PSTN).	139
C.2.3 Using the photoelectric effect to explain how incident light causes charge to build up in a pixel.	113	C.4.3 Use of mobile phones in multimedia communication.	140
C.2.4 Digitisation of an image on a CCD.	113	C.4.4 Issues arising from the use of mobile phones.	140
C.2.5 Quantum efficiency of a pixel in a CCD.	115	Answers to Digital Technology	527
C.2.6 Magnification of a CCD.	115		
C.2.7 Resolution of a CCD.	116		
C.2.8 Image quality of a CCD.	116		
C.2.9 Uses of CCDs.	118		
C.2.10 Image retrieval in a CCD.	119		
C.2.11 Questions on CCDs.	122		

This image shows a full page of a document template. It consists of approximately 30 evenly spaced horizontal dotted lines across the entire width of the page, providing a guide for handwriting or typing. There are no margins, text, or other markings present.

Relativity and Particle Physics

Dot Point	Page	Dot Point	Page
Relativity: D1-D3 are identical to H1-H3.			
D1 Introduction to relativity	143	D.4.5 Antiparticles.	171
Frames of reference		D.4.6 Pauli exclusion principle.	171
D.1.1 Frames of reference.	143	Fundamental interactions	
D.1.2 Galilean transformations.	145	D.4.7 Types of fundamental interactions.	171
D.1.3 Questions on relative velocities using Galilean transformation equations.	146	D.4.8 Exchange particles.	172
D2 Concepts and postulates of special relativity	151	D.4.9 Uncertainty principle for time and energy.	172
D.2.1 Inertial frames of reference.	151	Feynman diagrams	
D.2.2 Two postulates of the special theory of relativity.	152	D.4.10 Feynman diagrams.	173
D.2.3 Simultaneity.	154	D.4.11 Using Feynman diagrams to calculate probabilities for fundamental processes.	173
D3 Relativistic kinematics	159	D.4.12 Virtual particles.	176
Time dilation		D.4.13 Range for interactions involving the exchange of a particle.	176
D.3.1 Concept of a light clock.	159	D.4.14 Pair annihilation and pair production.	177
D.3.2 Proper time interval.	159	D.4.15 Predicting particle processes using Feynman diagrams.	177
D.3.3 Time dilation formula.	159	D5 Quarks	181
D.3.4 Graphing relative velocity versus the Lorentz factor.	160	D.5.1 Types of quarks.	181
D.3.5 Questions on time dilation.	161	D.5.2 Quark content of hadrons.	182
Length contraction		D.5.3 Quark content of the proton and neutron.	182
D.3.6 Proper length.	164	D.5.4 Law of conservation of baryon number.	183
D.3.7 Length contraction.	164	D.5.5 Spin structure of hadrons.	184
D.3.8 Questions on length contraction.	164	D.5.6 Need for colour in forming bound states of quarks.	185
Particles: D4 and D5 are identical to J1 and J3.			
D4 Particles and Interactions	167	D.5.7 Colour of quarks and gluons.	185
Description and classification of particles		D.5.8 Concept of strangeness.	187
D.4.1 Elementary particles.	167	D.5.9 Quark confinement.	185
D.4.2 Identifying elementary particles.	167	D.5.10 Interaction between nucleons and the colour force between quarks.	185
D.4.3 Describing particles in terms of mass and quantum numbers.	168	Answers to Relativity and Particle Physics	541
D.4.4 Classifying particles according to spin.	170		

This image shows a full page of white paper with horizontal dotted lines. The lines are evenly spaced and run across the width of the page, providing a guide for handwriting or typing. There are no margins, text, or other markings on the page.

Dot Point	Page	Dot Point	Page
Core material: E1-E4 are core material for SL and HL. Extension material: E5-E6 are extension material for HL only.			
E1 Introduction to the Universe	191	Hertzsprung-Russell diagrams	
The Solar System and beyond		E.2.11 Regions of star types on a Hertzsprung-Russell (HR) diagram.	204
E.1.1 Structure of the Solar System.	191	E3 Stellar distances	211
E.1.2 Stellar clusters and constellations.	192	Parallax method	
E.1.3 Light year.	192	E.3.1 Parsecs.	211
E.1.4 Relative distances between stars.	193	E.3.2 Stellar parallax method.	211
E.1.5 Apparent motion of the stars.	193	E.3.3 Limitations of stellar parallax method.	211
E2 Stellar radiation and stellar types	195	E.3.4 Questions on stellar parallax.	211
Energy source		Absolute and apparent magnitudes	
E.2.1 Fusion as the main energy source of stars.	195	E.3.5 Apparent magnitude scale.	213
E.2.2 Equilibrium between radiation pressure and gravitational pressure in stable stars.	195	E.3.6 Absolute magnitude.	213
Luminosity		E.3.7 Questions on apparent magnitude, absolute magnitude and distance.	213
E.2.3 Luminosity of stars.	196	E.3.8 Questions on apparent brightness and apparent magnitude.	213
E.2.4 Apparent brightness of stars.	196	Spectroscopic parallax	
Wien's law and the Stefan-Boltzmann law		E.3.9 Estimating the luminosity of a star from its spectrum.	216
E.2.5 Comparing luminosities of stars using the Stefan-Boltzmann law.	197	E.3.10 Determining stellar distance using apparent brightness and luminosity.	216
E.2.6 Using Wien's law to explain the connection between the colour and temperature of stars.	197	E.3.11 Limitations of spectroscopic parallax.	217
Stellar spectra		E.3.12 Questions on stellar distances, apparent brightness and luminosity.	217
E.2.7 Deducing chemical and physical data for stars from atomic spectra.	199	Cepheid variables	
E.2.8 Classification system of spectral classes.	200	E.3.13 Nature of a Cepheid variable.	219
Types of stars		E.3.14 Relationship between period and absolute magnitude for Cepheid variables.	219
E.2.9 Types of stars.	202	E.3.15 Using Cepheid variables as 'standard candles'.	219
E.2.10 Characteristics of spectroscopic and eclipsing binary stars.	202	E.3.16 Determining the distance to a Cepheid variable.	219

Dot Point	Page	Dot Point	Page
E4 Cosmology	223	E.5.3 Changes during nucleosynthesis.	229
Olbers' parallax		Evolutionary paths of stars and stellar processes	
E.4.1 Newton's model of the Universe.	223	E.5.4 Applying the mass-luminosity relation.	232
E.4.2 Olbers' paradox.	223	E.5.5 Using the Chandrasekhar and Oppenheimer-Volkoff limits.	232
Big Bang model		E.5.6 Comparing the fate of a red giant and a red supergiant.	232
E.4.3 Red-shift of light from galaxies as evidence that the Universe is expanding.	224	E.5.7 Drawing evolutionary paths of stars on an HR diagram.	232
E.4.4 Space and time originated with the Big Bang.	224	E.5.8 Characteristics of pulsars.	235
E.4.5 Discovery of cosmic microwave background (CMB) radiation.	225	HL E6 Galaxies and the expanding Universe	237
E.4.6 Consistency of radiation in the microwave region with the Big Bang model.	225	Galactic motion	
E.4.7 Big Bang model as a resolution to Olbers' paradox.	225	E.6.1 Distribution of galaxies in the Universe.	237
Development of the Universe		E.6.2 Red-shift of light from distant galaxies.	237
E.4.8 Open, flat and closed models of the development of the Universe.	226	E.6.3 Questions on red-shift and recession speed of galaxies.	237
E.4.9 Critical density and the flat model.	227	Hubble's law	
E.4.10 Density of the Universe and development of the Universe.	227	E.6.4 Hubble's law.	238
E.4.11 Problems with determining the density of the Universe.	227	E.6.5 Limitations of Hubble's law.	238
E.4.12 Current scientific evidence for an open Universe.	226	E.6.6 Determining the Hubble constant.	238
E.4.13 International astrophysics research.	228	E.6.7 Estimating the age of the Universe using the Hubble constant.	238
E.4.14 Evaluating priorities for scientific research.	228	E.6.8 Questions on Hubble's law.	238
HL E5 Stellar processes and stellar evolution	229	E.6.9 Formation of light nuclei and atoms made possible by expansion of the Universe.	240
Nucleosynthesis		Answers to Astrophysics	557
E.5.1 Conditions for initiation of fusion in a star.	229		
E.5.2 Effect of a star's mass on the end product of nuclear fusion.	229		

Communications

Dot Point	Page	Dot Point	Page
Core material: F1-F4 are core material for SL and HL. Extension material: F5-F6 are extension material for HL only.			
F1 Radio communication	243	F3 Optic fibre transmission	261
F.1.1 Modulation of waves.	243	F.3.1 Critical angle and total internal reflection.	261
F.1.2 Carrier waves and signal waves.	243	F.3.2 Questions on refractive index and critical angle.	261
F.1.3 Amplitude modulation (AM) and frequency modulation (FM).	243	F.3.3 Transmission of light along an optic fibre.	261
F.1.4 Questions on modulation of carrier waves.	244	F.3.4 Effects of material dispersion and modal dispersion.	263
F.1.5 Graphing the power spectrum of a carrier wave.	244	F.3.5 Attenuation and questions on attenuation.	263
F.1.6 Sideband frequencies and bandwidth.	244	F.3.6 Variation with wavelength of the attenuation of radiation.	263
F.1.7 Questions on sideband frequencies and bandwidth.	244	F.3.7 Noise in an optic fibre.	271
F.1.8 Advantages and disadvantages of AM and FM radio.	248	F.3.8 Role of amplifiers and reshapers in optic fibre transmission.	271
F.1.9 Block diagram of an AM radio receiver.	248	F.3.9 Questions on optic fibres.	271
F2 Digital signals	251	F4 Channels of communication	273
F.2.1 Questions on conversion between binary and decimal numbers.	251	F.4.1 Different types of channels of communication.	273
F.2.2 Analog and digital signals.	253	F.4.2 Uses, advantages and disadvantages of wire pairs, coaxial cables, optic fibres and radio waves.	273
F.2.3 Advantages of digital transmission.	253	F.4.3 Geostationary satellites.	274
F.2.4 Transmission and reception of digital signals.	253	F.4.4 Communication frequencies for geostationary satellites.	274
F.2.5 Significance of the number of bits and bit-rate.	253	F.4.5 Advantages and disadvantages of communication satellites.	274
F.2.6 Time-division multiplexing.	255	F.4.6 Issues arising from satellite communication.	274
F.2.7 Questions on analog-to-digital conversion.	255	HL F5 Electronics	277
F.2.8 Consequences of digital communication on worldwide communications.	259	F.5.1 Properties of an ideal operational amplifier (op-amp).	277
F.2.9 Issues arising from access to the internet.	259	F.5.2 Drawing circuit diagrams for inverting and non-inverting amplifiers.	278



Dot Point		Page	Dot Point		Page
F.5.3	Deriving an expression for the gain of inverting and non-inverting amplifiers.	281	HL F6 Mobile phone system		291
			F.6.1	Areas divided into cells.	291
F.5.4	Using an operational amplifier circuit as a comparator.	283	F.6.2	Role of cellular exchange and public switched telephone network (PSTN).	291
F.5.5	Using a Schmitt trigger for reshaping digital pulses.	283	F.6.3	Use of mobile phones in multimedia communication.	292
F.5.6	Questions on circuits incorporating operational amplifiers.	286	F.6.4	Issues arising from the use of mobile phones.	292
			Answers to Communications		571

Electromagnetic Waves

Dot Point	Page	Dot Point	Page
Core material: G1-G4 are core material for SL and HL. Extension material: G5-G6 are extension material for HL only.			
G1 Nature of EM waves and light sources	295		
Nature and properties of EM waves			
G.1.1 Nature of electromagnetic (EM) waves.	295	G.2.6 Thin lens formula.	307
G.1.2 Regions of the electromagnetic spectrum.	295	G.2.7 Questions on the thin lens formula for a single convex lens.	307
G.1.3 Dispersion of EM waves.	299	Simple magnifying glass	
G.1.4 Dispersion and dependence of refractive index on wavelength.	299	G.2.8 Far point and near point for the unaided eye.	310
G.1.5 Transmission, absorption and scattering of radiation.	301	G.2.9 Angular magnification.	310
G.1.6 Examples of transmission, absorption and scattering of EM radiation.	301	G.2.10 Deriving an expression for angular magnification.	310
Lasers		Compound microscope and astronomical telescope	
G.1.7 Monochromatic and coherent sources of radiation.	303	G.2.11 Ray diagram for a compound microscope.	313
G.1.8 Laser light as a source of coherent light.	303	G.2.12 Ray diagram for an astronomical telescope.	313
G.1.9 Mechanisms for production of laser light.	303	G.2.13 Equation for angular magnification in an astronomical telescope.	313
G.1.10 Applications of lasers.	303	G.2.14 Questions on the compound microscope and astronomical telescope.	313
G2 Optical instruments	305	Aberrations	
G.2.1 Principal axis, focal point, focal length and linear magnification of a converging (convex) lens.	305	G.2.15 Spherical and chromatic aberration in lenses.	318
G.2.2 Power of a convex lens and diopetre.	305	G.2.16 Reducing spherical aberration in a lens.	318
G.2.3 Linear magnification.	307	G.2.17 Reducing chromatic aberration in a lens.	318
G.2.4 Constructing ray diagrams to locate images formed by convex lenses.	307	G3 Two-source interference of waves	321
G.2.5 Real and virtual images.	307	G.3.1 Observing interference between two sources.	321
		G.3.2 Principle of superposition and two-source interference.	321
		G.3.3 Young's double slit experiment.	321
		G.3.4 Questions on two-source interference.	321

Dot Point	Page	Dot Point	Page
G4 Diffraction grating	329	HL G6 Thin-film interference	341
Multiple-slit diffraction		Wedge films	
G.4.1 Effect of increasing the number of slits.	329	G.6.1 Production of interference fringes by a thin air wedge.	341
G.4.2 Diffraction grating formula.	329	G.6.2 Using wedge fringes to measure very small separations.	341
G.4.3 Using diffraction grating to measure wavelength.	329	G.6.3 Testing optical flats using thin-film interference.	341
G.4.4 Questions on diffraction grating.	329	G.6.4 Questions on wedge films.	341
HL G5 X-rays	333	Parallel films	
G.5.1 Production of X-rays.	333	G.6.5 Reflection of light and phase changes.	343
G.5.2 Drawing a typical X-ray spectrum.	333	G.6.6 Interference patterns and parallel films.	343
G.5.3 Origins of a characteristic X-ray spectrum.	333	G.6.7 Conditions for constructive and destructive interference.	343
G.5.4 Questions on X-rays.	333	G.6.8 White light and formation of coloured fringes.	344
X-ray diffraction		G.6.9 Differences between fringes formed by a parallel film and a wedge film.	344
G.5.5 Scattering of X-rays in crystals.	336	G.6.10 Applications of parallel thin films.	348
G.5.6 Bragg scattering equation.	336	G.6.10 Questions on parallel films.	348
G.5.7 Using cubic crystals to measure X-ray wavelength.	336	Answers to Electromagnetic Waves	589
G.5.8 X-ray crystallography.	336		
G.5.9 Questions on the Bragg equation.	336		

Relativity

Dot Point	Page	Dot Point	Page
This option is available at HL only.			
HL H1 Introduction to relativity	353	Mass and energy	
Frames of reference		H.4.4 Formula for equivalence of mass and energy.	379
H.1.1 Frames of reference.	353	H.4.5 Rest mass.	379
H.1.2 Galilean transformations.	355	H.4.6 Energy of a body at rest and its total energy when moving.	379
H.1.3 Questions on relative velocities using the Galilean transformation equations.	356	H.4.7 Why no object can ever attain the speed of light in a vacuum.	379
HL H2 Concepts and postulates of special relativity	361	H.4.8 Total energy of an accelerated particle.	379
H.2.1 Inertial frames of reference.	361	HL H5 Evidence to support special relativity	383
H.2.2 Two postulates of the special theory of relativity.	362	H.5.1 Muon decay as evidence to support special relativity.	383
H.2.3 Simultaneity.	364	H.5.2 Questions on muon decay.	383
HL H3 Relativistic kinematics	369	H.5.3 Michelson-Morley experiment.	384
Time dilation		H.5.4 Results and implications of Michelson-Morley experiment.	384
H.3.1 Concept of a light clock.	369	H.5.5 Pion decay experiments an indication that the speed of light in a vacuum is independent of its source.	386
H.3.2 Proper time interval.	369	HL H6 Relativistic momentum and energy	387
H.3.3 Time dilation formula.	369	H.6.1 Applying the relation for the relativistic momentum of particles:	387
H.3.4 Graphing relative velocity versus the Lorentz factor.	370	$p = \gamma m_0 u$	
H.3.5 Questions on time dilation.	371	H.6.2 Applying the formula for the kinetic energy of a particle: $E_k = (\gamma - 1)m_0 c^2$	387
Length contraction		H.6.3 Questions on relativistic momentum and energy.	387
H.3.6 Proper length.	374	HL H7 General relativity	389
H.3.7 Length contraction.	374	Equivalence principle	
H.3.8 Questions on length contraction.	374	H.7.1 Gravitational mass and inertial mass.	389
H4 Some consequences of special relativity	377	H.7.2 Einstein's principle of equivalence.	389
Twin paradox		H.7.3 Principle of equivalence and bending of light rays in a gravitational field.	389
H.4.1 Time dilation and the 'twin paradox'.	377		
H.4.2 Hafele-Keating experiment.	377		
Velocity addition			
H.4.3 Questions on relativistic addition of velocities.	378		

Dot Point	Page	Dot Point	Page
H.7.4 Principle of equivalence and time slowing down near a massive body.	389	Gravitational red-shift	
Spacetime		H.7.12 Gravitational red-shift.	394
H.7.5 Concept of spacetime.	391	H.7.13 Questions on frequency shifts between different points in a uniform gravitational field.	394
H.7.6 Movement of objects in spacetime.	391	H.7.14 Questions on gravitational time dilation formula.	394
H.7.7 Gravitational attraction and warping of spacetime by matter.	391	HL H8 Evidence to support general relativity	397
Black holes		H.8.1 Experiment for the bending of EM waves by a massive object.	397
H.7.8 Black holes.	392	H.8.2 Gravitational lensing.	
H.7.9 Schwarzschild radius.	392	H.8.3 Experiment that provides evidence for gravitational red-shift.	397
H.7.10 Calculating the Schwarzschild radius.	392		
H.7.11 Questions on time dilation close to a black hole.	392	Answers to Relativity	611

Medical Physics

Dot Point	Page	Dot Point	Page
This option is available at HL only.		I.2.5	X-ray imaging techniques in medicine. 427
HL I1 The ear and hearing	403	I.2.6	Computed tomography (CT). 432
I.1.1	Structure of the human ear. 403	Ultrasound	
I.1.2	Pressure variations in air and cochlear fluid. 405	I.2.7	Ultrasound generation and detection. 433
I.1.3	Range of audible frequencies for humans. 407	I.2.8	Acoustic impedance. 434
I.1.4	Observed loudness and change in intensity. 407	I.2.9	Questions on acoustic impedance. 434
I.1.5	Logarithmic response of the ear to intensity. 407	I.2.10	A-scan and B-scan imaging. 436
I.1.6	Sound intensity and intensity level. 409	I.2.11	Factors affecting choice of diagnostic imaging. 436
I.1.7	Intensity levels and discomfort threshold. 409	NMR and lasers	
I.1.8	Questions on sound intensity levels. 409	I.2.12	Basic principles of nuclear magnetic resonance (NMR) imaging. 438
I.1.9	Effects of short-term and long-term exposure to noise. 418	I.2.13	Lasers in clinical diagnosis and therapy. 440
I.1.10	Hearing tests and audiograms. 418	HL I3 Radiation in medicine	443
HL I2 Medical imaging	423	I.3.1	Terms used in dosimetry. 443
X-rays		I.3.2	Precautions in radiation situations. 444
I.2.1	X-ray attenuation coefficient and half-value thickness. 423	I.3.3	Balanced risk. 444
I.2.2	Deriving the relation between attenuation coefficient and half-value thickness. 423	I.3.4	Physical, biological and effective half-life. 447
I.2.3	Questions on attenuation coefficient and half-value thickness. 423	I.3.5	Questions on radiation dosimetry. 447
I.2.4	X-ray detection, recording and display techniques. 427	I.3.6	Radiation therapy for cancer. 448
		I.3.7	Questions on choice of radioisotope. 450
		I.3.8	Questions on diagnostic applications. 450
		Answers to Medical Physics	625

This image shows a full page of white paper with horizontal dotted lines, resembling notebook paper. The lines are evenly spaced and run across the width of the page. There is no handwriting or other markings on the paper.

Particle Physics

Dot Point	Page	Dot Point	Page
This option is available at HL only.			
HL J1 Particles and interactions	455		
Description and classification of particles		J.2.3	Linear accelerators and cyclotrons. 469
J.1.1 Elementary particles.	455	J.2.4	Structure and operation of a synchrotron. 471
J.1.2 Identifying elementary particles.	455	J.2.5	Bremsstrahlung radiation. 472
J.1.3 Describing particles in terms of mass and quantum numbers.	456	J.2.6	Advantages and disadvantages of accelerators. 473
J.1.4 Classifying particles according to spin.	458	J.2.7	Questions on production of particles in accelerators. 473
J.1.5 Antiparticles.	459	Particle detectors	
J.1.6 Pauli exclusion principle.	459	J.2.8 Structure and operation of particle detectors.	479
Fundamental interactions		J.2.9 International aspects of particle research.	482
J.1.7 Types of fundamental interactions.	459	J.2.10 Economic and ethical implications of particle research.	482
J.1.8 Exchange particles.	460	HL J3 Quarks	483
J.1.9 Uncertainty principle for time and energy.	460	J.3.1 Types of quarks.	483
Feynman diagrams		J.3.2 Quark content of hadrons.	484
J.1.10 Feynman diagrams.	461	J.3.3 Quark content of the proton and neutron.	484
J.1.11 Using Feynman diagrams to calculate probabilities for fundamental processes.	461	J.3.4 Law of conservation of baryon number.	485
J.1.12 Virtual particles.	464	J.3.5 Spin structure of hadrons.	486
J.1.13 Range for interactions involving the exchange of a particle.	464	J.3.6 Need for colour in forming bound states of quarks.	487
J.1.14 Pair annihilation and pair production.	465	J.3.7 Colour of quarks and gluons.	487
J.1.15 Predicting particle processes using Feynman diagrams.	465	J.3.8 Concept of strangeness.	489
HL J2 Particle accelerators and detectors	469	J.3.9 Quark confinement.	487
Particle accelerators		J.3.10 Interaction between nucleons and the colour force between quarks.	487
J.2.1 High energies and particles of large mass.	469	HL J4 Leptons and the standard model	491
J.2.2 High energies to resolve small particles.	469	J.4.1 Three-family structure in the standard model.	491
		J.4.2 Lepton number in each family.	491



Dot Point			Page	Dot Point			Page
J.4.3	Questions on conservation laws in particle reactions.	492		HL J6	Cosmology and strings	497	
J.4.4	Significance of the Higgs boson.	494		J.6.1	Temperature change since the Big Bang.	497	
HL J5	Experimental evidence for the quark and standard models	495		J.6.2	Particle interactions in the early Universe.	497	
J.5.1	Deep inelastic scattering.	495		J.6.3	Particles and antiparticles in the early Universe.	497	
J.5.2	Results of deep inelastic scattering experiments.	495		J.6.4	Predominance of matter over antimatter.	497	
J.5.3	Asymptotic freedom.	495		J.6.5	Theory of strings.	499	
J.5.4	Neutral current.	496		Answers to Particle Physics			641
J.5.5	Neutral current as evidence for the standard model.	496					



DOT POINT

OPTION A

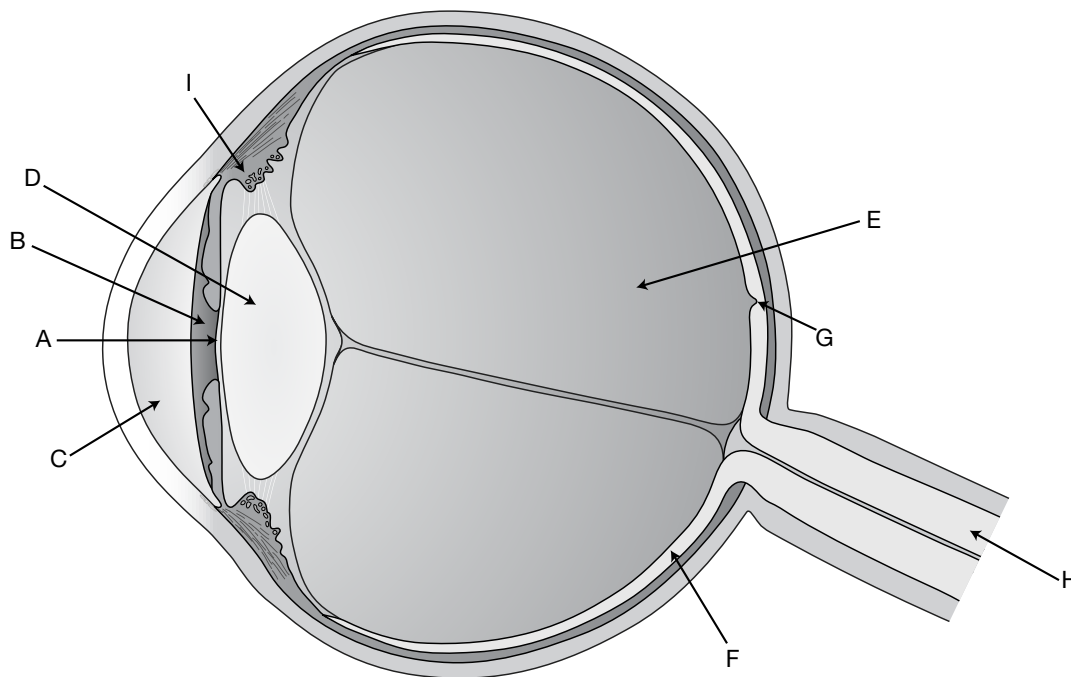
Sight and Wave Phenomena

[illegible]

A1 The eye and sight. © IBO 2007

A.1.1 Describe the basic structure of the human eye. © IBO 2007

A.1.1.1 Identify the parts of the human eye by annotating the diagram.



A.1.1.2 Outline two processes used by the eye to produce the clearest image of a distant object on the retina.

.....

.....

A.1.1.3 Describe the nature of the image formed on the retina.

.....

A.1.1.4 Using the components of the eye listed below, identify the sequence in which light travels from an object to the retina.

Vitreous humour, retina, aqueous humour, lens, cornea.

.....

A.1.1.5 An eye is often described as the equivalent of a camera. Complete the table by identifying the parts of the eye that are equivalent to the camera parts.

Camera part	Aperture	Lens	Screen	Focusing system
Human eye part				

A.1.2 State and explain the process of depth of vision and accommodation. © IBO 2007

A.1.2.1 Identify which of the following is the best estimate of the focal length of a 'normal' human eye.

- (A) 10 cm
- (B) 25 cm
- (C) 50 cm
- (D) Infinity

A.1.2.2 Explain what is meant by the near point.

.....

.....

A.1.2.3 Explain what is meant by the far point.

.....

.....

A.1.2.4 Discuss what is meant by accommodation. Include in your discussion how it is achieved by the human eye for the near point and the far point.

.....

.....

.....

.....

A.1.2.5 When a 'normal' human eye is most relaxed, identify the distance away from the eyes at which an object will be in focus.

- (A) The object is at the focal length of the 'normal' eye, i.e. about 25 cm.
- (B) The object is about 10 m away.
- (C) The object is at infinity.
- (D) The object is very close to the eye, about 10-15 cm.

A.1.2.6 Draw ray diagrams to help explain the following.

(a) Explain why an object at the near point is not clear.

.....

.....

(b) Explain why an object at the far point is seen with the least stress on the eyes.

.....

.....

A.1.2.7 Explain what is meant by depth of vision.

.....

.....

A.1.2.8 Explain why depth of vision is essential for us.

.....

.....

A.1.2.9 Discuss three methods used by the human eye to achieve depth of vision.

.....

.....

.....

.....

.....

A.1.2.10 Identify which one of the following is a significant process that occurs in the human eye.

- (A) Reflection.
- (B) Refraction.
- (C) Diffraction.
- (D) Polarisation.

A.1.2.11 Identify which one of the following is the best description of the image formed in the human eye.

- (A) Real, upright, reduced and without colour.
- (B) Virtual, reduced, inverted and coloured.
- (C) Real, inverted, and reduced.
- (D) Real, actual size and inverted.

A.1.2.12 Explain what is meant by stereoscopic vision, referring to the processes involved in achieving this.

.....

.....

.....

.....

A.1.2.13 Identify which one of the following is predominantly responsible for accommodation.

- (A) Ciliary muscles.
- (B) Pupil.
- (C) Iris.
- (D) Cornea.

A.1.2.14 If an eye does not focus an image on the retina and instead at a spot too close or too far away, what could be done?

.....

.....

A.1.2.15 Identify the location in the human eye with the greatest concentration of cones.

- (A) Iris.
- (B) Fovea.
- (C) Cornea.
- (D) Optic nerve.

A.1.3 **State that the retina contains rods and cones, and describe the variation in density across the surface of the retina.** © IBO 2007

A.1.3.1 Identify where rods and cones are situated in the eye.

.....

.....

A.1.3.2 Identify which one of the following statements best describes the relative properties of rods and cones at low light intensity.

- (A) Rods are sensitive and cones are relatively insensitive.
- (B) Both rods and cones are sensitive.
- (C) Both rods and cones are insensitive.
- (D) Cones are sensitive and rods are relatively insensitive.

A.1.3.3 Identify which one of the following statements best describes the relative properties of rods and cones for light response and colour.

- (A) Cones have a slow response and are sensitive to colour.
- (B) Rods have a fast response but are insensitive to colour.
- (C) Cones have a fast response but are insensitive to colour.
- (D) Rods have a slow response and are sensitive to colour.

A.1.3.4 Outline the consequence of the very low concentration of rods around the fovea.

.....

.....

A.1.3.5 Identify which one of the following is closest in value to the number of rods and cones in a 'normal' human eye.

- (A) About 6.5 million rods and 120 million cones.
- (B) About equal number of rods and cones, 100 million each.
- (C) About 50 million rods and 100 million cones.
- (D) About 120 million rods and 6.5 million cones.

A.1.3.6 Identify the three colours that cones are sensitive to and identify the one colour to which the cones are most sensitive.

.....

.....

A.1.3.7 The ratio of the number of rods to the number of cones in the human eye is about:

- (A) 1:20
- (B) 20:1
- (C) 1:100
- (D) 100:1

A.1.4 Describe the function of the rods and of the cones in photopic and scotopic vision. © IBO 2007

A.1.4.1 Explain what is meant by photopic vision and scotopic vision.

.....

.....

A.1.4.2 Explain whether rods or cones are used in each of photopic vision and scotopic vision.

.....

.....

.....

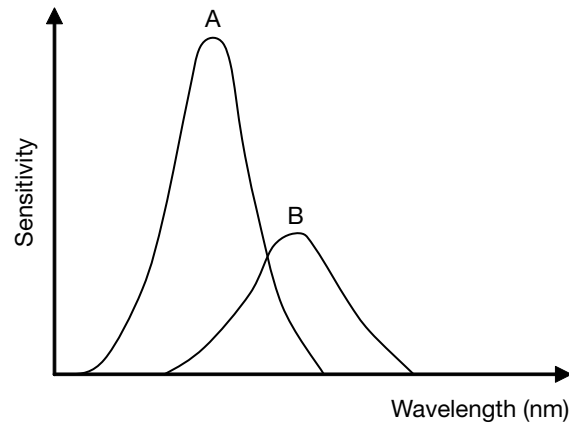
A.1.4.3 Referring to rods and cones, outline the cause of colour blindness.

.....

.....

.....

A.1.4.4 The light spectral response graph for scotopic and photopic vision of a 'normal' human eye is shown.



(a) Identify which graph is of rods and which is of cones. Explain your answer.

.....

.....

(b) Which of the graphs is an appropriate representation of scotopic vision? Explain your reasoning.

.....

.....

A.1.4.5 Suggest why vision at night is a slow response.

.....

.....

.....

A.1.4.6 Explain why there is a blind spot in our eye.

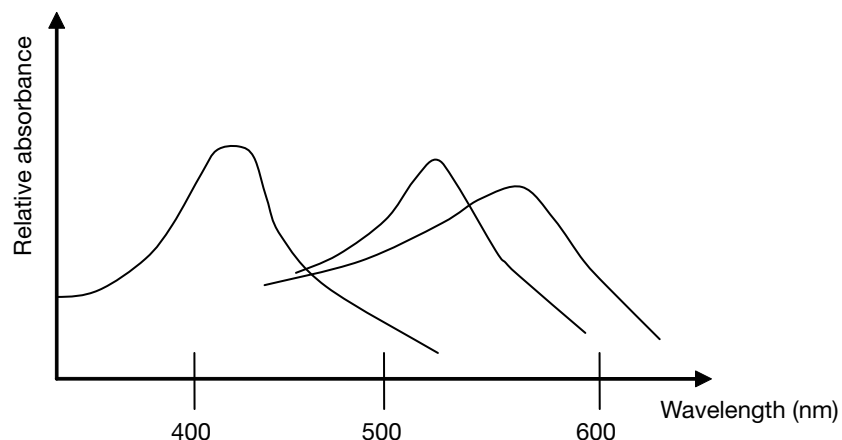
.....

.....

A.1.4.7 Identify which are the three wavelengths of maximum absorbance for cones, called short (S), medium (M) and long (L) respectively.

- (A) 400 nm, 600 nm and 900 nm.
- (B) 430 nm, 530 nm and 630 nm.
- (C) 450 nm, 550 nm and 650 nm.
- (D) 430 nm, 530 nm and 560 nm.

A.1.4.8 The spectral response curves for a person's three types of cones, S, M and L are shown.

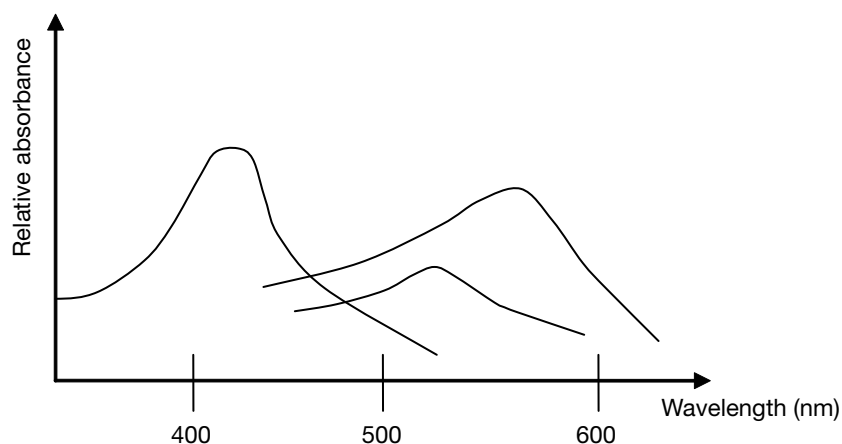


- (a) Annotate each curve as S, M or L.
- (b) Sketch the light response curve for rods on the same graph, showing the relative location of the principal wavelength for rods.
- (c) Discuss whether it is appropriate to nominate the S, M and L spectra for cones as blue, green and red respectively.

.....

.....

- (d) The light spectral response graph for another person is different, as shown. Describe this person's perception of coloured images.



.....

.....

.....

A.1.4.9 Suggest why rods are the main providers of the sense of vision at night.

.....

.....

A.1.4.10 Suggest why vision at night generally does not allow great clarity of colour.

.....

.....

A.1.5 **Describe colour mixing of light by addition and subtraction.** © IBO 2007

A.1.5.1 Describe the main processes for colour addition and colour subtraction.

.....

.....

A.1.5.2 Identify the resulting colours when the following occur.

- (a) Red and green colours are added.
- (b) Red, green and blue colours are added.
- (c) All secondary colours are added.

A.1.5.3 Explain what primary colours are and identify examples.

.....

.....

A.1.5.4 Explain what secondary colours are and identify examples.

.....

.....

A.1.5.5 Referring to absorption and reflection of light, explain why a wall painting with blue pigment appears blue.

.....

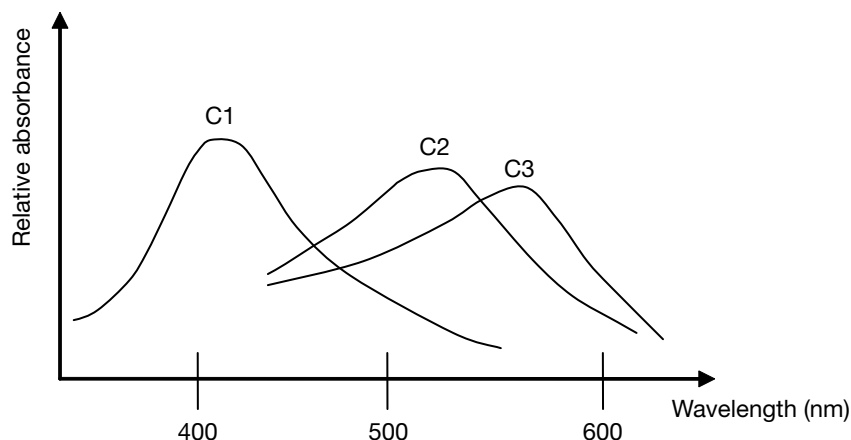
.....

A.1.5.6 Referring to absorption and reflection of light, explain why white light when transmitted through a certain filter appeared red.

.....

.....

A.1.5.7 The graph shows the spectral colour response for three kinds of cones, C1, C2 and C3.



(a) Identify which cones are short, medium and long.

.....

(b) Explain why the cones are called short, medium and long, referring to the corresponding colours they are most sensitive to.

.....

.....

.....

A.1.5.8 A certain filter blocks out blue light from a white light source.

(a) Explain why this is an instance of colour subtraction and colour addition.

.....

.....

(b) Deduce the colour of the transmitted light.

.....

.....

A.1.5.9 Identify what colour a red glass will appear when blue light is shone on it.

- (A) Red.
- (B) Blue.
- (C) Black.
- (D) Magenta.

A.1.6 Discuss the effect of light and dark, and colour, on the perception of objects. © IBO 2007

A.1.6.1 Explain how a two-dimensional picture can achieve an effect of three dimensions.

.....

.....

.....

A.1.6.2 Discuss how colour can be used to make a room look smaller, larger, warmer or cooler than it actually is.

(a) Smaller.

.....

.....

(b) Larger.

.....

.....

(c) Warmer.

.....

.....

(d) Cooler.

.....

.....

A.1.6.3 Discuss how shadows from buildings can be interpreted by the brain in our perception of a building's size.

.....

.....

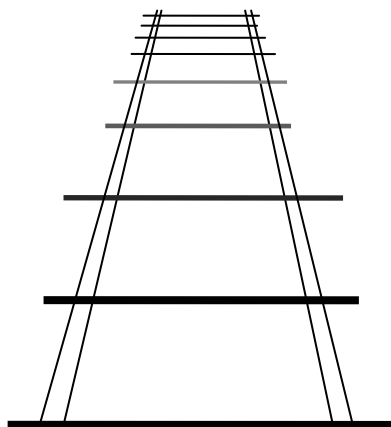
.....

A.1.6.4 Explain how spatial depth can be realised on a flat surface, using an illustration as an example.

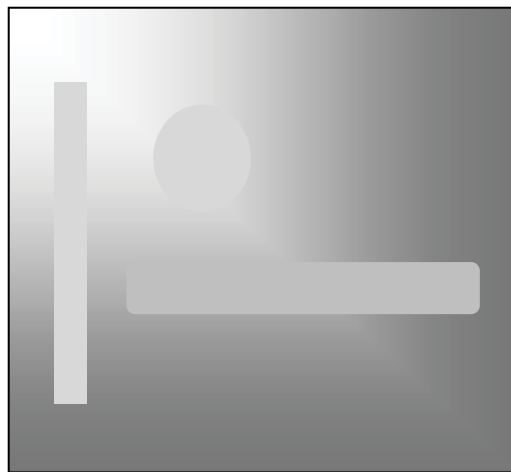
.....

.....

A.1.6.5 For the drawings below, describe the illusion created, referring to both the factual information and the illusion.



A



B

.....

.....

.....

.....

.....

[illegible]

A.2.1 Describe the nature of standing (stationary) waves. © IBO 2007

A.2.2 Explain the formation of one-dimensional standing waves. © IBO 2007

Note that A.2.1 and A.2.2 are combined and questions carry A.2.1 numbers.

A.2.1.1 Explain the formation of standing waves, using the example of a string tied at both ends.

A.2.1.2 A wave set up in a string is called a standing wave when:

- (A) The positions of the nodes and antinodes do not change with time.
- (B) The positions of nodes are fixed with time but the positions of antinodes can change.
- (C) There is no movement of any string element.
- (D) The amplitudes of all elements in the string are the same.

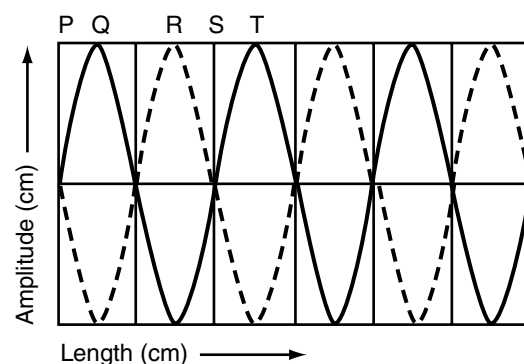
A.2.1.3 Which of the following statements (one or more) correctly describes energy propagation in a standing wave in a string fixed at both ends?

- (A) A decrease in energy would result in a less number of nodes and antinodes.
- (B) An increase in energy would result in an increased amplitude of the standing wave.
- (C) There is no net flow of energy from one fixed end to the other end of the string.
- (D) Different string elements have different amounts of kinetic energy at any given time.

A.2.1.4 The diagram illustrates a standing wave set up by a 1000 Hz oscillator in a string fixed at both ends and of length 60.0 cm.

(a) Complete the following table.

Maximum amplitude	
Wavelength	
Time period	
A location which is a displacement node	
A location which is a displacement antinode	
Two particles of the string which are in phase	
Two particles of the string which are out of phase	



(b) Since $v = f\lambda$, explain what v refers to in the context of the table in (a).

A.2.1.5 Identify the factors that affect the amplitude of a standing wave. When will maximum amplitude result?

.....

.....

A.2.1.6 Explain what conditions lead to the formation of nodes and antinodes in an air column, making reference to phase and amplitude.

.....

.....

.....

.....

A.2.1.7 A standing wave is set up in an air column. Explain why the position of the displacement antinode is also called the position of the pressure node, and vice versa.

.....

.....

.....

A.2.3 Discuss the modes of vibration of strings and air in open and closed pipes. © IBO 2007

A.2.3.1 When a string, fixed at both ends, is plucked a standing wave is established. In this context, determine whether the following statements are true or false.

	Statement	True or false?
(a)	In the fundamental standing wave, there is only one displacement antinode but two nodes.	
(b)	Standing waves are created by two waves of the same frequency and wavelength travelling in opposite directions.	
(c)	The fundamental standing wave is the loudest harmonic heard because the string vibrates with the highest amplitude.	
(d)	Only the first two harmonics correspond to resonant frequencies; the other harmonics do not.	
(e)	For a string of length L , the n th resonant frequency is given by $f_n = n \frac{v}{2L}$, where v is the speed of sound.	
(f)	For a string of length L , the n th resonant frequency is given by $f_n = n \frac{v}{4L}$, where v is the speed of sound.	
(g)	The third harmonic is a frequency three times that of the fundamental.	
(h)	The third harmonic is a frequency two times that of the fundamental.	
(i)	All harmonics, not just the even ones, are possible in a guitar string.	
(j)	Only the odd number harmonics are possible in a guitar string.	
(k)	A standing wave in a guitar string is set up due to the reflection from fixed ends, and this reflection is $\lambda/2$ out of phase with the incident wave.	
(l)	The reflection from fixed ends in a guitar string are in phase with the incident wave thereby reinforcing the incident wave and causing resonance.	
(m)	In the fundamental standing wave, there is only one pressure antinode but two nodes.	

A.2.3.2 A flute is an example of a pipe open at both ends. The air column in the flute can be made to vibrate by blowing through a small hole in the flute. The energy provided by blowing is used to vibrate the air molecules in a way that sets up a standing wave.

For a flute in which a standing wave is set up complete the following sentences by circling the best option.

- (a) Soundwaves are reflected from open ends with a phase change of one wavelength/half a wavelength/one quarter wavelength.
- (b) At the ends of the flute there is a destructive/constructive interference and pressure nodes/antinodes.
- (c) The pressure of air is maximum at the ends/in the middle of the flute and the pressure at the ends/in the middle is equal to air pressure.
- (d) The displacement of air molecules is maximum/minimum at the ends of the flute and for the fundamental, the displacement of air molecules is maximum/minimum in the middle of the flute.

A.2.3.3 For an air column open at both ends, such as that in a flute, identify whether the following statements are true or false.

	Statement	True or false?
(a)	The harmonics are very similar to that of a string tied at both ends.	
(b)	The harmonics are very similar to that of a string tied at one end and held loosely at the other end.	
(c)	The motion of air particles is the least where there is a pressure antinode and most where there is a pressure node.	
(d)	The motion of air particles is the least where there is a pressure node and most where there is a pressure antinode.	
(e)	The frequency of the third harmonic is three times that of the fundamental.	
(f)	The frequency of the third harmonic is 2/3 times that of the second harmonic.	

A.2.3.4 On the outline of a tube containing an air column sketch (a) the displacement and (b) pressure modes of vibration for the fundamental, 2nd harmonic, and 3rd harmonic.

(a) Displacement modes.

Fundamental

2nd harmonic

3rd harmonic

(b) Pressure modes.

Fundamental

2nd harmonic

3rd harmonic

A.2.3.5 The human ear is an example of an air column closed at one end and open at the other. Complete the following sentences by circling the best option.

- (a) Soundwaves are reflected from the closed end of the air column with a change of phase of $\lambda/2$ nil. Therefore there is constructive/destructive interference at the closed end and a pressure node/ antinode results.
- (b) The fundamental mode of vibration will have the relationship $L = \frac{\lambda}{4} / L = \frac{\lambda}{2}$ where L is the length of the air column. Only odd/even number of harmonics are possible.

A.2.3.6 Explain why the frequency of sound in the air above water seems to increase as water is poured into a pipe closed at one end.

.....

.....

.....

A.2.3.7 Derive a relationship between the wavelength of the n th harmonic standing wave to the length of the string or air column for each of the following cases. Use the derived relationships to establish appropriate formulas for calculating the frequency of the n th harmonic.

- (a) String fixed at both ends.

.....

.....

.....

- (b) Pipe closed at one end.

.....

.....

.....

- (c) Pipe open at both ends.

.....

A.2.3.8 Complete the table by calculating the following ratios.

Ratio of:	Ratio is:
Fundamental frequency to the 3rd harmonic for a string.	
2nd harmonic frequency to the 4th harmonic for a string.	
2nd harmonic frequency to the 3rd harmonic for a pipe open at both ends.	
The wavelength of the fundamental to the 3rd harmonic for a string.	
Fundamental frequency to the next higher frequency for a pipe closed at one end.	
The wavelength of the 2nd harmonic to the 4th harmonic for a pipe open at both ends.	

.....

.....

.....

A.2.3.9 What length of a string fixed at both ends will result in a fundamental frequency of 312 Hz? The speed of the wave in the string is 815 m s^{-1} .

A.2.3.10 The end correction for a pipe is used to correct the measured frequency which differs from the calculated value due to the three-dimensional vibrations of the air molecules. The correction depends on the diameter, d of the pipe in accordance with the equation: true wavelength, $\lambda = 4(L + 0.4d)$ for a closed ended pipe and $\lambda = 4(L + 0.8d)$ for an open ended pipe where L = length of the pipe.

What would be the end correction for a pipe of radius 0.1 m closed at one end where the length of the air column is 0.15 m? How would this end correction be applied?

A.2.4 Compare standing waves and travelling waves. © IBO 2007

A.2.4.1 Explain the difference in the way energy of the oscillator is structured in a standing wave versus a travelling wave.

A.2.4.2 Discuss the variation in amplitude of string elements when a string carries a travelling wave and contrast this to when the string sets up a standing wave.

A.2.4.3 Both travelling and standing waves can be represented by sinusoidal graphs. Sketch a graphical (sinusoidal) representation of a travelling wave and a standing wave and discuss how wavelengths and time periods can be determined in each case.

A.2.4.4 Discuss the movement of various string elements in a string with respect to phase difference when the string bears (a) a travelling wave and (b) a standing wave.

A.2.5 Solve problems involving standing waves. © IBO 2007

A.2.5.1 A guitar string fixed at both ends is raised and let go so that it sets up the fundamental mode of standing wave vibration. It is found to pass through the mean position 20 times per second in the initial moments of the vibration when damping effects can be ignored. What is the time period of the note produced?

A.2.5.2 Standing wave experiments are carried out in an air column open at both ends. Calculate the wavelength of each standing wave in the following table. Each row may represent a different standing wave.

Information	Wavelength (m)
Distance between the 1st node and 2nd node is 0.4 m	
Distance between the 1st node and 3rd antinode is 0.6 m	
Distance between the 1st antinode and 2nd node is 0.3 m	

A.2.5.3 Two tuning forks of frequency 512 Hz are set up on a stand 0.33 m apart. When the forks start to vibrate, a fundamental standing wave is set up in the air space between them.

(a) What is meant by a ‘standing wave’ in this context?

(b) Why does a standing wave form in this set-up?

(c) Estimate the speed of sound from the information given.

A.2.5.4 A guitar string of length 0.5 m is tied at both ends. When an external 512 Hz source is used, a loud clear sound is heard indicative of the fundamental.

(a) What is the speed of the wave in the guitar string?

.....

.....

(b) What will be the frequency of the 4th harmonic?

.....

.....

.....

(c) With what length of this string can the second harmonic frequency be heard almost as loud as the fundamental?

.....

.....

.....

A.2.5.5 A 25 cm long flute is modelled as an air column open at both ends.
The speed of sound in air is 340 m s^{-1} .

(a) Calculate:

(i) The wavelength of the fundamental λ_0 .

(ii) The frequency of the 3rd harmonic f_3 .

(iii) The wavelength of the 4th harmonic f_4 mode of vibration.

.....

.....

.....

.....

(b) Draw a diagram showing the location of the pressure nodes and antinodes of the 2nd harmonic.

A.2.5.6 A 467.2 Hz tuning fork gives a strong resonance when held over a container filled with water to an appropriate level as shown.

- (a) When the fundamental is sounded, the air column is 16.6 cm high. Estimate the speed of sound.

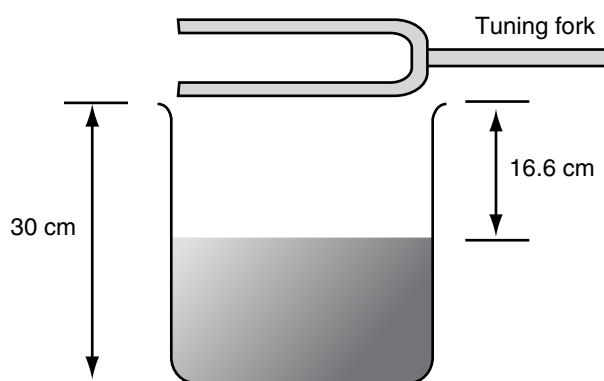
.....

.....

.....

.....

.....



- (b) Another resonance, much softer than the fundamental is also heard. What could be the frequency of this resonance?

.....

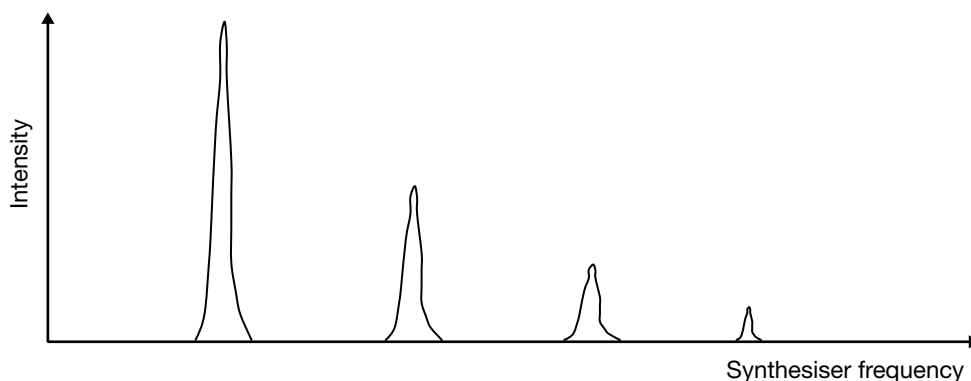
.....

- (c) If the water is now drained from the container, what frequency is needed for the fundamental to be heard?

.....

.....

A.2.5.7 The changing frequencies from a frequency synthesiser are sounded over an air column open at both ends. The sound intensity measured in the air column of length 0.5 m is then plotted as a function of incident frequencies and the following graph is obtained. In a separate measurement, the speed of sound in air was determined to be 345 m s^{-1} .



- (a) Estimate the frequencies of all the observed resonances.

.....

.....

.....

- (b) How will the graph change if the bottom end of the tube is closed?

.....

.....

A.2.5.8 The six different guitar strings produce different notes even though they are the same length as frequency also depends on the tension in the string and mass per unit length.

The fundamental frequency is given by $f = \frac{1}{2L} \sqrt{\frac{T}{M}}$, where L = length of the string, T = tension and M = mass per unit length.

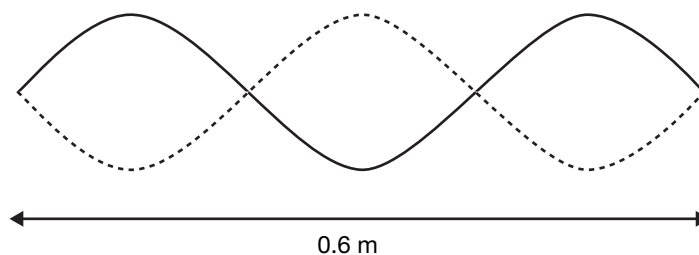
Find the fundamental frequency produced by a string 0.3 m long and of mass 0.8 g when put under a tension of 60 N.

.....

.....

.....

A.2.5.9 For a wave pattern set up in a string that is not the fundamental, the speed of a wave in the string is given by $v = \sqrt{\frac{T}{M}}$, where M = mass per unit length, also called the linear density. A guitar string of length 0.6 m and linear density 5.0 g/m is under a tension of 100 N. A standing wave pattern is set up as shown. Find (i) speed, (ii) wavelength and (iii) frequency of the travelling wave which has resulted in this standing wave.



.....

.....

.....

.....

.....

.....

This image shows a full page of white paper with horizontal dotted lines. The lines are evenly spaced and run across the width of the page, providing a guide for handwriting or typing. There are no margins, text, or other markings on the page.

A.3.1 Describe what is meant by the Doppler effect. © IBO 2007

A.3.2 Explain the Doppler effect by reference to wavefront diagrams for moving-detector and moving-source situations. © IBO 2007

Note that A.3.1 and A.3.2 are combined and questions carry A.3.1 numbers.

A.3.1.1 A police car with sirens blaring comes your way and then passes you, all at constant speed while you stay still.

(a) Explain the perceived variation in the frequency that you hear.

.....

.....

(b) Explain why the frequency appears to be different.

.....

.....

.....

A.3.1.2 The following diagrams show the wave patterns produced by a source, S as it moves towards or away from a stationary observer at point Z.

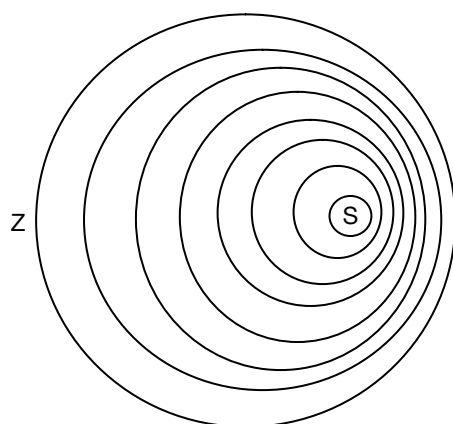


Figure A

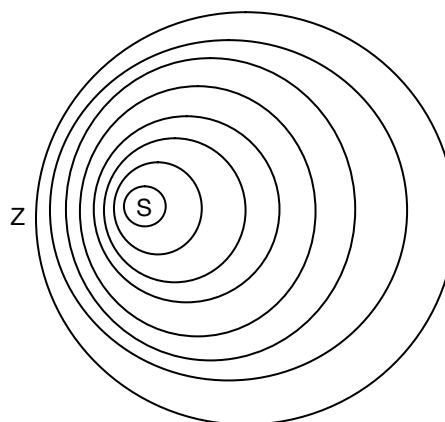


Figure B

(a) Discuss, which figure, A or B shows the source moving towards the observer.

.....

.....

(b) How would the figures change if the source was stationary and the observer was moving towards or away from the source?

.....

.....

A.3.1.3 The Doppler effect equation is given by $f' = f \left[\frac{1}{1 \pm \frac{v_s}{v}} \right]$ for a moving source or $f' = f \left[1 \pm \frac{v_o}{v} \right]$ for a moving observer.

(a) Show that for a moving source, the equation can be written as $f' = f \left[\frac{v}{v \pm v_s} \right]$.

(b) Develop a combined general equation for the Doppler effect.

(c) By referring to the Doppler effect equation(s), for the two instances when v_o is the same as v_s , discuss whether you would expect the detected frequency to be greater in one case or the same.

A.3.1.4 Complete the following table by determining the change in frequency an observer will record in each instance.

Observer	Source	Change in observed frequency
Moving towards the source	Stationary	
Moving away from source	Stationary	
Stationary	Moving away	
Stationary	Moving towards	
Moving towards source	Moving towards observer	
Moving away from source	Moving away from observer	

A.3.1.5 With the aid of a wavefront diagram explain why the frequency of a wave appears to increase as the source moves towards a stationary observer.

A.3.3 Apply the Doppler effect equations for sound. © IBO 2007

A.3.4 Solve problems on the Doppler effect for sound. © IBO 2007

Note that A.3.3 and A.3.4 are combined and questions carry A.3.3 numbers.

Take the speed of sound in air to be 340 m s^{-1} , unless otherwise stated.

A.3.3.1 A police car drives at 120 kph sending out a siren at 1000 Hz.

What will be the apparent frequency to a bystander for the following? *Hint:* Use $f' = f \left[\frac{v}{v \pm v_s} \right]$.

- (a) As the police car approaches her.

.....

.....

.....

- (a) As the police car goes away.

.....

.....

.....

A.3.3.2 To a stationary observer an ambulance travelling at constant speed seems to have a frequency of 1400 Hz when approaching him and 1200 Hz when going away. Calculate:

- (a) The speed of the ambulance.

.....

.....

.....

- (a) The actual frequency emitted by the ambulance.

.....

.....

.....

A.3.3.3 Jeremy is driving at a constant speed towards a stationary traffic inspector and sounds a horn at a frequency of 800 Hz. To the traffic inspector, the horn sounded to be 850 Hz.

- (a) How fast was Jeremy driving?

.....

.....

.....

- (b) What would the inspector measure the frequency to be as Jeremy continues on driving away from the inspector?

.....

.....

.....

(c) What is the wavelength of the soundwaves detected by the inspector in parts (a) and (b)?

.....

.....

.....

(d) What is the wavelength of the sound emitted by Jeremy's car?

.....

.....

A.3.3.4

(a) When an aircraft travels faster than the speed of sound (mach 1), it is said to have 'broken the sound barrier' and to an observer on the ground, a loud explosive sound is heard. Draw a diagram showing the source (plane) and the wavefronts approaching an observer and explain what causes the loud sound.

.....

.....

.....

(b) If the aircraft now travels faster than the speed of sound ($> \text{mach } 1$) then two loud explosive sounds are often heard. Draw a diagram showing the source (plane) and the wavefronts approaching an observer and explain what causes the two loud sounds.

.....

.....

.....

A.3.5 Solve problems on the Doppler effect for electromagnetic waves using the approximation

$$\Delta f = \frac{v}{c} f. \quad \text{© IBO 2007}$$

A.3.5.1 A galaxy close to us has an atmosphere rich in a gas whose spectral line on Earth is measured to be 530 nm but that from the galaxy is 480 nm. Explain the significance of the change in wavelength.

.....

A.3.5.2 For objects moving at $v \ll c$, $\Delta f = \frac{v}{c} f$.

(a) According to this relationship, what is the measured frequency of a 1.53×10^9 Hz source moving towards the Earth at $0.08 c$ relative to Earth being stationary?

.....

.....

(b) If the source moved away from the Earth at the same speed, what would be the measured frequency?

.....

.....

A.3.5.3 A distant galaxy moving at a constant speed relative to the Earth is emitting a frequency of 2.00×10^{12} Hz but it is measured on Earth as 2.15×10^{12} Hz.

(a) Discuss whether the galaxy is moving towards or away from Earth.

.....

.....

(b) Determine the speed of the galaxy relative to Earth.

.....

.....

.....

A.3.5.4 For galaxies moving close to the speed of light, the Doppler equation used is: $f' = f \left[\frac{1}{1 \pm \frac{v_s}{c}} \right]$.

(a) Show that for a galaxy emitting a wavelength $= \lambda$, the observed wavelength on Earth $\lambda' = \lambda \left(\frac{c \pm v_s}{c} \right)$.

.....

.....

.....

(b) Explain how the speed of a galaxy moving away from us is measured by the red-shift.

.....

.....

.....

A.3.5.5 A distant galaxy moving away from Earth at a constant speed of $0.01\ c$ relative to Earth is emitting a wavelength of $520.0\ \text{nm}$.

(a) What would be the measured wavelength on Earth?

.....

.....

.....

(b) Use the Doppler equation for light $\lambda = \lambda_0 \left(1 + \frac{v_s}{v}\right)$ to find the measured wavelength on Earth and compare it with the value in part (a).

.....

.....

.....

(c) What is the measured value of red-shift? What information does it provide?

.....

.....

A.3.6 Outline an example in which the Doppler effect is used to measure speed. © IBO 2007

A.3.6.1 A source emits a soundwave of frequency $1000\ \text{Hz}$ and is set into motion with a uniform speed of $15\ \text{m s}^{-1}$ towards an observer who records the frequency as $1045\ \text{Hz}$. What is the speed of sound in these conditions?

.....

.....

.....

.....

A.3.6.2 The speed of motor vehicles is checked by a stationary police radar gun by firing a high-frequency wave pulse at the vehicle and measuring its echo.

(a) Show that the frequency shift observed by the stationary police car would be $\Delta f = \frac{2fv_{\text{car}}}{v_{\text{wave}}}$.

.....

.....

.....

.....

.....

(b) In one measurement, the police radar gun sends out a sound pulse of frequency $24.0\ \text{GHz}$ at an incoming car. The reflected pulse is received at a frequency of $19.7\ \text{GHz}$. Estimate the speed of the incoming car.

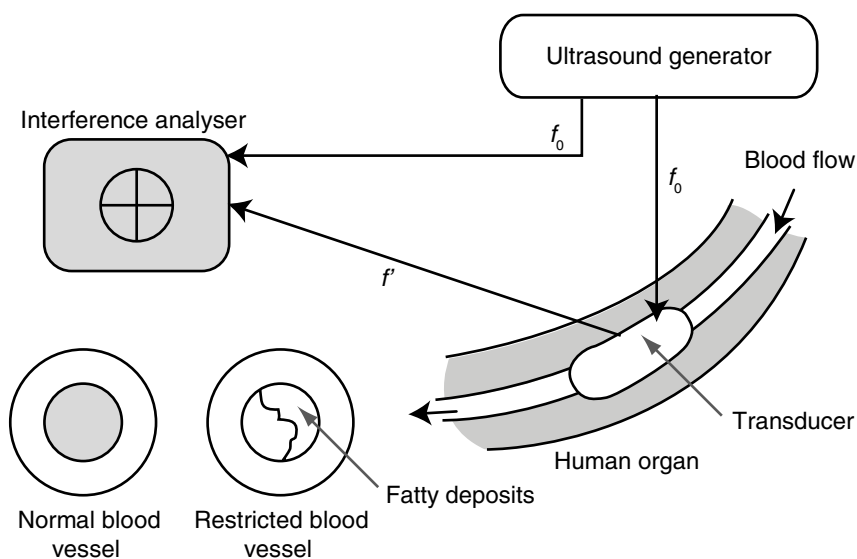
.....

.....

.....

A.3.6.3

Ultrasound is a frequency of soundwaves higher than 20 000 Hz so that humans cannot hear it. Ultrasound is also the name used for the non-invasive diagnostic technique to obtain information about human organs and blood vessels as well as checking on the foetus during pregnancy. Arterial blockages can be deciphered where blood flows faster than normal in a constricted cross-section. Take the speed of sound in blood as 1480 m s^{-1} .



- (a) In one person, 3.00 MHz ultrasound waves are sent to a normal blood vessel where blood flows at 15.0 m s^{-1} . What would be the frequency of the reflected soundwave?
-
-
-
-
- (b) In an arterial measurement, the 3.00 MHz wave is reflected back as a 3.12 MHz wave. What is the speed of blood in this artery? You may wish to comment on the significance of increased speed in this artery.
-
-
-
-

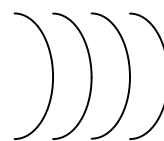
[illegible]

Diffraction at a single slit

A.4.1 Sketch the variation with angle of diffraction of the relative intensity of light diffracted at a single slit. © IBO 2007

A.4.1.1 An electromagnetic wave is incident on a single slit opening as shown in the figure. The distance between wavefronts is the wavelength. Draw a diagram to illustrate how the intensity of the pattern would change along the screen.

Incident electromagnetic wave



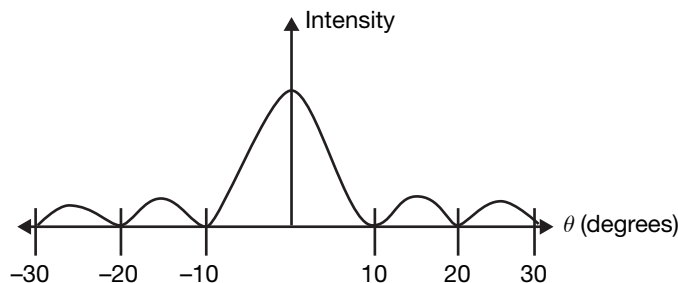
Screen

A.4.1.2 Explain why a diffraction pattern is seen with a single slit.

.....

.....

A.4.1.3 The intensity of interference fringe as a function of angle θ is shown in the figure below. The angle θ is the angle between the centre of the slit to the location of the fringe.



(a) Explain why the intensity of the peaks reduces on either side of the central maximum.

.....

.....

(b) Discuss how the central maximum is different from other fringes.

.....

.....

A.4.2 Derive the formula $\theta = \frac{\lambda}{b}$ for the position of the first minimum of the diffraction pattern produced at a single slit. © IBO 2007

A.4.3 Solve problems involving single-slit diffraction. © IBO 2007

Note that A.4.2 and A.4.3 are combined and questions carry A.4.2 numbers.

A.4.2.1 Consider the figure which shows the location of the 1st order dark fringe (first minimum).

(a) What is the relationship between path difference and wavelength for the first minimum?

.....

.....

.....

(b) With reference to the figure, derive a relationship between θ , λ and b for the first minimum.

.....

.....

.....

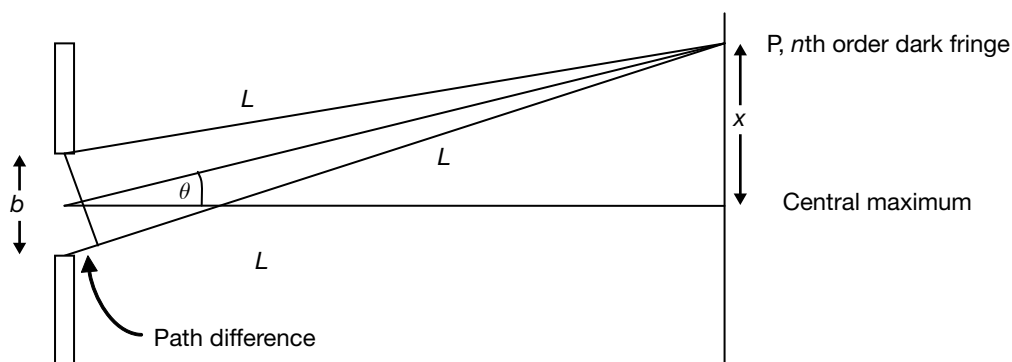
(c) Write the condition for the n th order dark fringe.

.....

(d) Write the condition for the n th order bright fringe, not including the central maximum.

.....

A.4.2.2 Consider a single-slit pattern with a monochromatic light source as shown in the figure.



(a) For L to be much larger than b and θ to be a small angle, show that for the n th order dark fringe $\frac{x}{L} = \frac{n\lambda}{b}$, where b and λ are of comparable magnitude and x is half the width of the central maximum.

.....

.....

.....

.....

- (b) Show that for the n th order bright fringe $\frac{x}{L} = \frac{(n + \frac{1}{2})\lambda}{b}$. Note that the relationship is opposite to that for double-slit interference.

.....

.....

.....

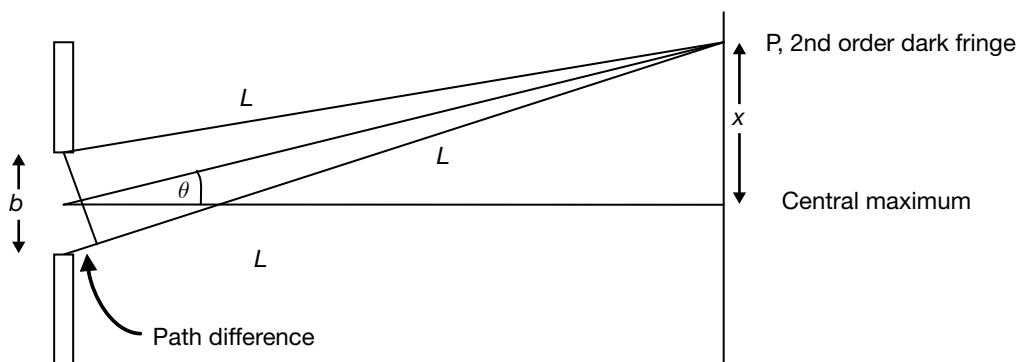
- (c) A 500 nm light passes through an opening of 1×10^{-5} m. What is the angle θ to the (i) 1st minimum and (ii) 3rd minimum?

.....

.....

.....

A.4.2.3 A monochromatic light of wavelength 500 nm is incident on a gap of width 0.09 mm. A screen is placed 2.5 m from the gap.



- (a) Estimate the distance x from the centre of the central maximum to the second order bright fringe.

.....

.....

.....

- (b) What is the thickness of the central maximum?

.....

.....

.....

- (c) What is the angular width of the central maximum?

.....

.....

.....

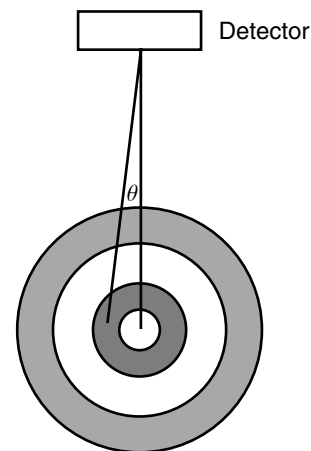
A.4.2.4 Monochromatic light of wavelength 520 nm is shone through a single slit and a diffraction pattern is obtained on a screen. Calculate the slit width, b , when the first minimum band is at $\theta = 10^\circ$.

A.4.2.5 What is the wavelength of the monochromatic light beam which, when shone through a single slit of width $2.0 \mu\text{m}$ gives the first minimum at an angle $\theta = 15^\circ$?

A.4.2.6 What is the wavelength of the monochromatic light beam which, when shone through a single slit of width $2.0 \mu\text{m}$ gave the first maximum at an angle $\theta = 18^\circ$?

A.4.2.7 If a single slit is replaced by a circular aperture of diameter b , then the first minimum is located at an angle θ , such that $\sin \theta = 1.22 \frac{\lambda}{d}$, where θ is the angle from the central axis to the circular pattern of the first minimum.

When a 550 nm monochromatic light beam shines through an aperture of diameter $1.2 \mu\text{m}$, what would be the angle θ ?



A.5.1 Sketch the variation with angle of diffraction of the relative intensity of light emitted by two point sources that has been diffracted at a single slit. © IBO 2007

A.5.1.1 What is meant by resolution in the context of images formed through lenses?

.....

.....

A.5.1.2 Outline how you distinguish which of two optical systems has the better resolution.

.....

.....

A.5.1.3 Outline two factors which affect the resolution of an optical system.

.....

.....

A.5.1.4 Describe the image of a one point object due to a circular aperture.

.....

A.5.1.5 Describe, referring to sketches of diffraction patterns, how the images of two point sources on a single screen are affected as the sources are brought closer together.

.....

.....

.....

A.5.2 State the Rayleigh criterion for images of two sources to be just resolved. © IBO 2007

A.5.3 Describe the significance of resolution in the development of devices such as CDs and DVDs, the electron microscope and radio telescopes. © IBO 2007

Note that A.5.2 and A.5.3 are combined and questions carry A.5.2 numbers.

A.5.2.1 For a single point source, the angular half-width of the central maximum is given by $\theta = 1.22 \frac{\lambda}{b}$. Compare this expression to a single rectangular slit: $\sin \theta = \frac{\lambda}{a}$, where a = slit width.

.....

.....

.....

A.5.2.2 Recall the Rayleigh criterion for two sources and illustrate this with an appropriate diagram.

.....

.....

A.5.2.3 Outline the significance of the Rayleigh criterion for wavelength of light used in imaging.

.....

.....

.....

A.5.2.4 The resolving power of a microscope is the smallest distance s between two points to be barely resolved.

(a) What is the relationship between s , f , θ and b , where f = focal length and b = aperture diameter?

.....

.....

(b) A smaller resolving power gives a better resolution. Which of the two electromagnetic radiations, red light or radio waves, would give a better resolution?

.....

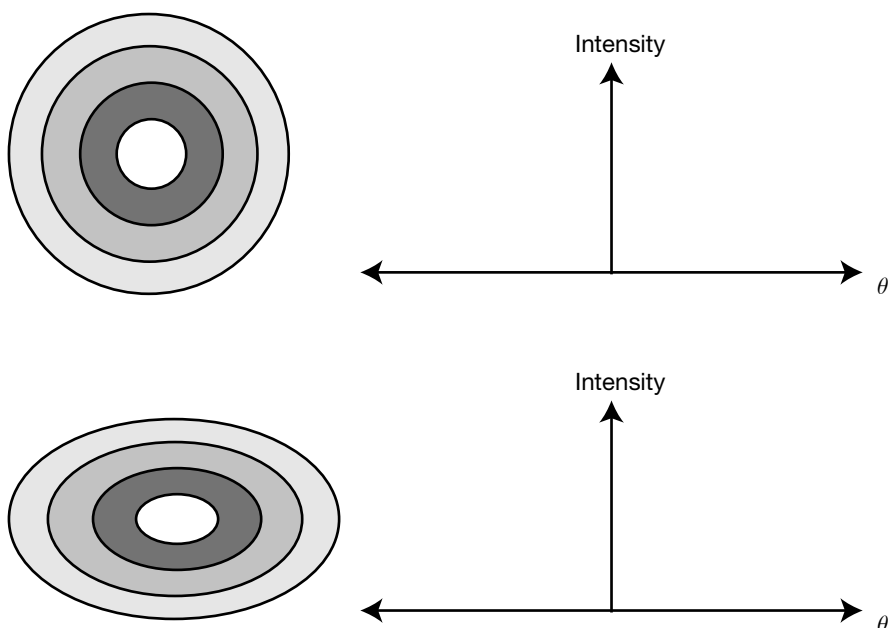
.....

(c) What is the smallest resolving power possible for any given wavelength with a particular lens?

.....

.....

- A.5.2.5** Two point sources are imaged through a single slit and the patterns are shown below. Sketch the intensity versus angle graphical patterns for the two situations.



A.5.4 Solve problems involving resolution. © IBO 2007

- A.5.4.1** A convex (converging) lens of focal length $f = 20.0$ cm and aperture $b = 40$ mm just resolves two point objects using a red light of wavelength 680 nm.

(a) Find θ in radians, the angular separation between the central maxima peaks.

.....

.....

(b) Which light, yellow ($\lambda = 580$ nm) or blue ($\lambda = 450$ nm) would give a better resolution? Justify your answer with calculations.

.....

.....

.....

- A.5.4.2** A remote-operated small aircraft flying at an altitude of 10 km takes images of terrains with a camera of aperture 50 mm. For the following calculations you may assume that light of wavelength 600 nm is the principal light received.

(a) Calculate the angle θ between two point objects on the ground which could just be resolved.

.....

.....

(b) What is the separation distance between the two point sources?

.....

.....

- (c) If the aircraft was flying at a lower altitude of 1 km what separation distance between the points could just be resolved now?

A.5.4.3 A space telescope just resolves two distant stars using visible light, $\lambda = 600 \text{ nm}$. It has an aperture of 4.00 m.

- (a) What is the angle θ between the two point sources?

- (b) Using radio waves, $\lambda = 0.05 \text{ m}$. What is the angle θ now?

- (c) If radio waves are used, what could be done to improve the resolution?

A.5.4.4 To a pedestrian, the front lights of a Rolls Royce are just resolved at a certain time of night. The lights are 1.8 m apart and are predominantly of $\lambda = 570 \text{ nm}$. In your calculations you may assume the diameter of the eye lens to be 2.1 mm. What is the theoretical distance between the pedestrian and the car at which the lights are just resolved? Comment on your findings.

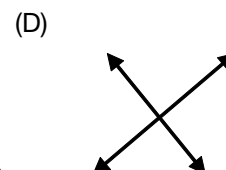
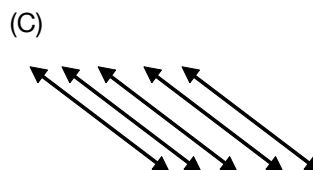
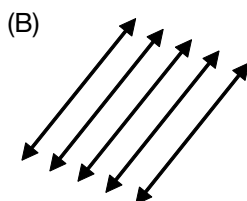
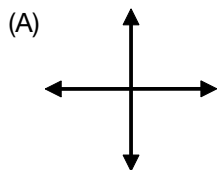
A.5.4.5 Explain why electron microscopes give better resolution than optical microscopes.

A.5.4.6 On a clear day an observer in an airplane is just able to resolve two points on the ground known to be 5 m apart. The principal wavelength used to resolve the objects is 600 nm and the aperture diameter of the eye lens is 1.8 mm. How high above the ground is the airplane?

A.6.1 Describe what is meant by polarised light. © IBO 2007**A.6.1.1** Describe what is meant by plane polarised light.

.....

.....

A.6.1.2 The following diagrams show oscillations of electric field vectors.

(a) Which of the diagrams, one or more, illustrate plane polarised light?

.....

(b) Which pair of diagrams could represent polariser and analyser?

.....

(c) Which of the diagrams, one or more, represent unpolarised light? Explain.

.....

A.6.1.3 Outline what is meant by plane polarised light in terms of electric field vector and direction of wave propagation.

.....

.....

A.6.2 Describe polarisation by reflection. © IBO 2007**A.6.3 State and apply Brewster's law.** © IBO 2007

Note that A.6.2 and A.6.3 are combined and questions carry A.6.2 numbers.

A.6.2.1 Explain how reflection causes polarisation.

.....

.....

.....

A.6.2.2 Explain how polarised sunglasses work to reduce glare.

.....

.....

.....

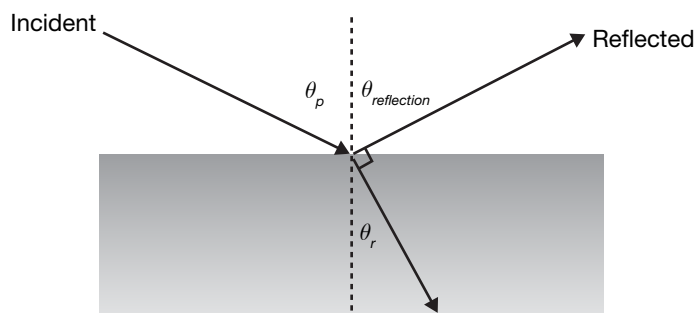
A.6.2.3 Discuss what is meant by polarising angle, with reference to Brewster's law and a beam of light travelling from air to water.

A.6.2.4 Explain the significance of Brewster's angle, making reference to angles of reflected and refracted rays. You may wish to draw an appropriate diagram.

A.6.2.5 Why are diamonds cut at Brewster's angle?

A.6.2.6 The refractive index of ethanol is 1.46. An incident beam of light shines on a container full of ethanol at Brewster's angle.

(a) What is the magnitude of Brewster's angle?



(b) What is the magnitude of the angle of refraction?

(c) What is the magnitude of the angle of reflection?

A.6.4 Explain the terms polariser and analyser. © IBO 2007

A.6.4.1 Explain the terms polariser, polaroid and analyser.

A.6.4.2 Under what conditions of the polariser and analyser would all light be blocked?

A.6.4.3 The transverse movement of a rope passing through a slit is used to illustrate plane polarised light. Discuss why this is an acceptable analogy.

A.6.4.4 Explain the outcome when a beam of light is passed through two polarising sheets as outlined below passing through sheet 1 first. Identify which sheet is the polariser and which is the analyser.

(a) Sheet 1 and sheet 2 have vertical polarising direction.

(b) Sheet 1 has a vertical polarising direction and sheet 2 horizontal.

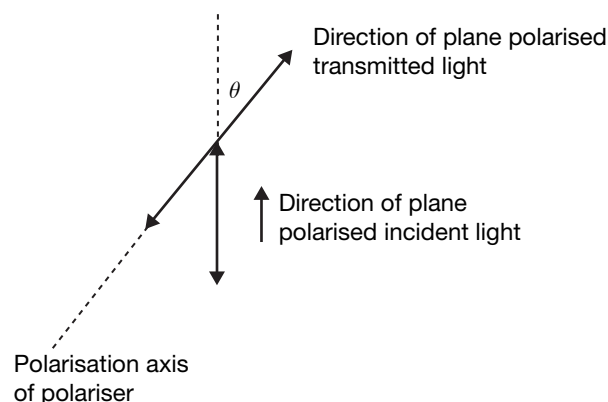
(c) Sheet 1 has a horizontal polarising direction and sheet 2 is at 45° to the vertical.

A.6.5 Calculate the intensity of a transmitted beam of polarised light using Malus' law. © IBO 2007

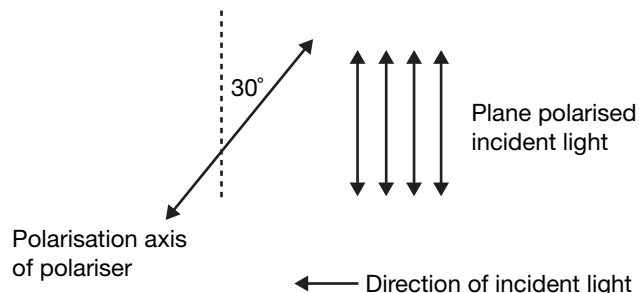
A.6.6 Describe what is meant by an optically active substance. © IBO 2007

Note that A.6.5 and A.6.6 are combined and questions carry A.6.5 numbers.

A.6.5.1 Explain Malus' law, i.e. why the intensity of plane polarised transmitted light I is related to the intensity of plane polarised incident light I_0 on a polariser, at an angle of θ as $I = I_0 \cos^2 \theta$.



A.6.5.2 A vertically plane polarised light passes a polaroid film whose polarisation axis is at 30° to the vertical. What is the ratio of intensity of transmitted light:intensity of incident light?



A.6.5.3 An unpolarised light of intensity 10.0 W m^{-2} passes through a polariser and then through an analyser such that the axis of the analyser is at 70° to that of the polariser.

(a) What is the intensity of the polarised light as it passes through the first polariser? Explain your answer.

.....

.....

.....

(b) Calculate the intensity of the polarised light after transmission through the second polariser.

.....

.....

(c) What further angle must the second polariser be turned through so that no light passes?

.....

.....

(d) What angle must the second polariser be turned through so that the intensity of light is the same as that incident on it?

.....

.....

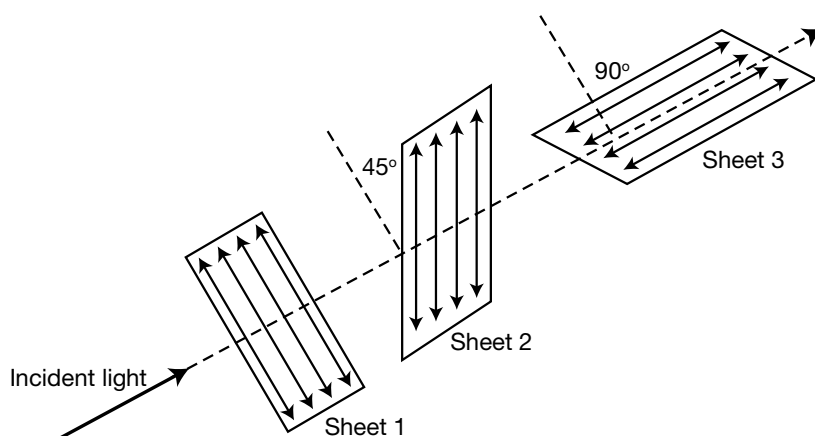
A.6.5.4 Explain what an optically active substance is, giving two examples.

.....

.....

.....

A.6.5.5 A beam of unpolarised light of intensity I_0 is passed through three sheets of polarising material. The first sheet has a vertical plane of polarisation at right angles to the path of the incident light. The second sheet is at 45° to the first and the third sheet has a horizontal plane of polarisation compared to the first.



(a) What fraction of light intensity emerges from the first sheet and what is the nature of the light?

.....

.....

.....

- (b) What fraction of light intensity emerges from the second sheet and what is the nature of the light?

.....

.....

.....

- (c) What fraction of light intensity emerges from the third sheet and what is the nature of the light?

.....

.....

.....

A.6.7 Describe the use of polarisation in the determination of the concentration of certain solutions. © IBO 2007

A.6.8 Outline qualitatively how polarisation may be used in stress analysis. © IBO 2007

A.6.9 Outline qualitatively the action of liquid-crystal displays (LCDs). © IBO 2007

Note that A.6.7, A.6.8 and A.6.9 are combined and questions carry A.6.7 numbers.

- A.6.7.1** Describe how polarisation may be used to find the concentration of sugar in blood, as a test for diabetes, making reference to parameters that need to be fixed.

.....

.....

.....

.....

.....

A.6.7.2 The optical activity of a sugar-containing solution is used to measure its concentration in accordance with the formula: $r_{\text{specific}} = \frac{r_{\text{observed}}}{L \times C}$, where r refers to the rotation angle in radians, C is the concentration in g/mL and L is the length of the solution in the path of the beam.

- (a) Identify some substances where the above technique can be useful.

.....

.....

- (b) Suggest why some materials have positive and some negative values of specific rotation angle.

.....

.....

- (c) Suggest why a specific temperature of solution and a specific wavelength of light are required for standardised testing of sugar solutions.

.....

.....

- (d) If the test solution is replaced with one double its concentration, the rotation angle would:

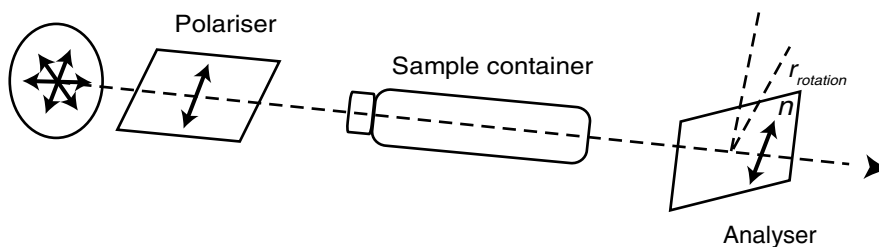
- (A) Double.
- (B) Halve.
- (C) Remain unchanged.
- (D) Increase four times.

A.6.7.3 Outline how stress in glasses and plastics can be studied using polarisation.

.....

.....

A.6.7.4 A polarimeter using a Na-D line of 589 nm is used to determine the rotation angle r_{rotation} for a sugar solution of concentration 0.09 g/100 mL. Given that the specific rotation angle for sugar is $+66.5^\circ$, find the rotation angle for the solution. Suggest some errors which may occur in such an estimate. The length, L , of the sample container is 0.2 dm.



A.6.7.5 LCD is an acronym for:

- (A) Liquid crystal diode.
- (B) Liquid crystal display.
- (C) Long crystal diode.
- (D) Linear crystal display.

A.6.7.6 LCDs are primarily based on the principle of:

- (A) Diffraction.
- (B) Interference.
- (C) Polarisation.
- (D) The Doppler effect.

A.6.7.7 State some applications where LCDs are used.

.....

A.6.7.8 State what is meant by pixel.

.....

A.6.7.9 Discuss the chemical and physical nature of liquid crystals.

.....

.....

A.6.7.10 Explain how the liquid crystals are organised in desired orientations in an LCD.

.....

.....

A.6.7.11 Discuss, with the aid of an appropriate diagram, the structure of a simple LCD.

.....

.....

.....

.....

A.6.7.12 Draw a sketch showing the direction of liquid crystal molecules in an LCD with no voltage and then with voltage applied to it. Explain, with reference to the diagrams how the change of orientation affects the output image.

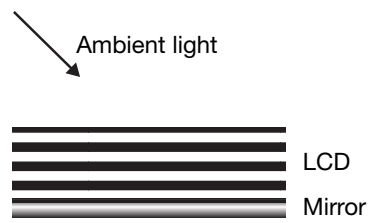
.....

.....

.....

.....

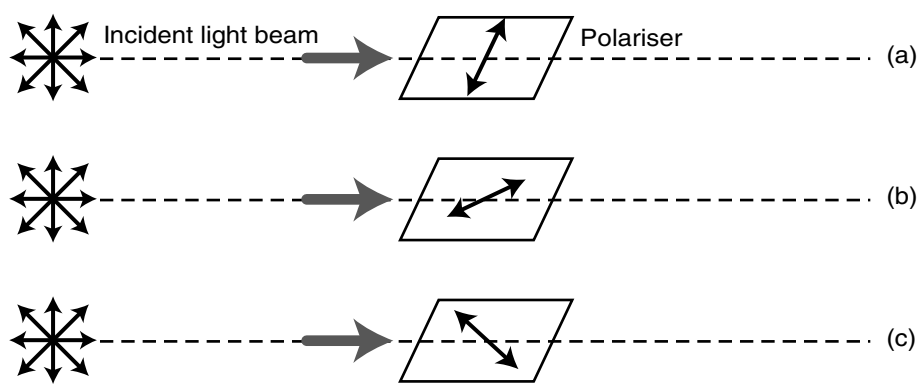
A.6.7.13 The diagram shows a simple schematic of an LCD arrangement in a calculator. Explain how the LCD gives the output corresponding to the number 9.



A.6.7.14 Explain in simple terms how colour is introduced in pixels.

A.6.10 Solve problems involving the polarisation of light. © IBO 2007

A.6.10.1 An unpolarised beam of light of intensity 5.0 W m^{-2} , is shone through different polarisers, one at a time. State the intensity of polarised light in each case. Explain your answer.

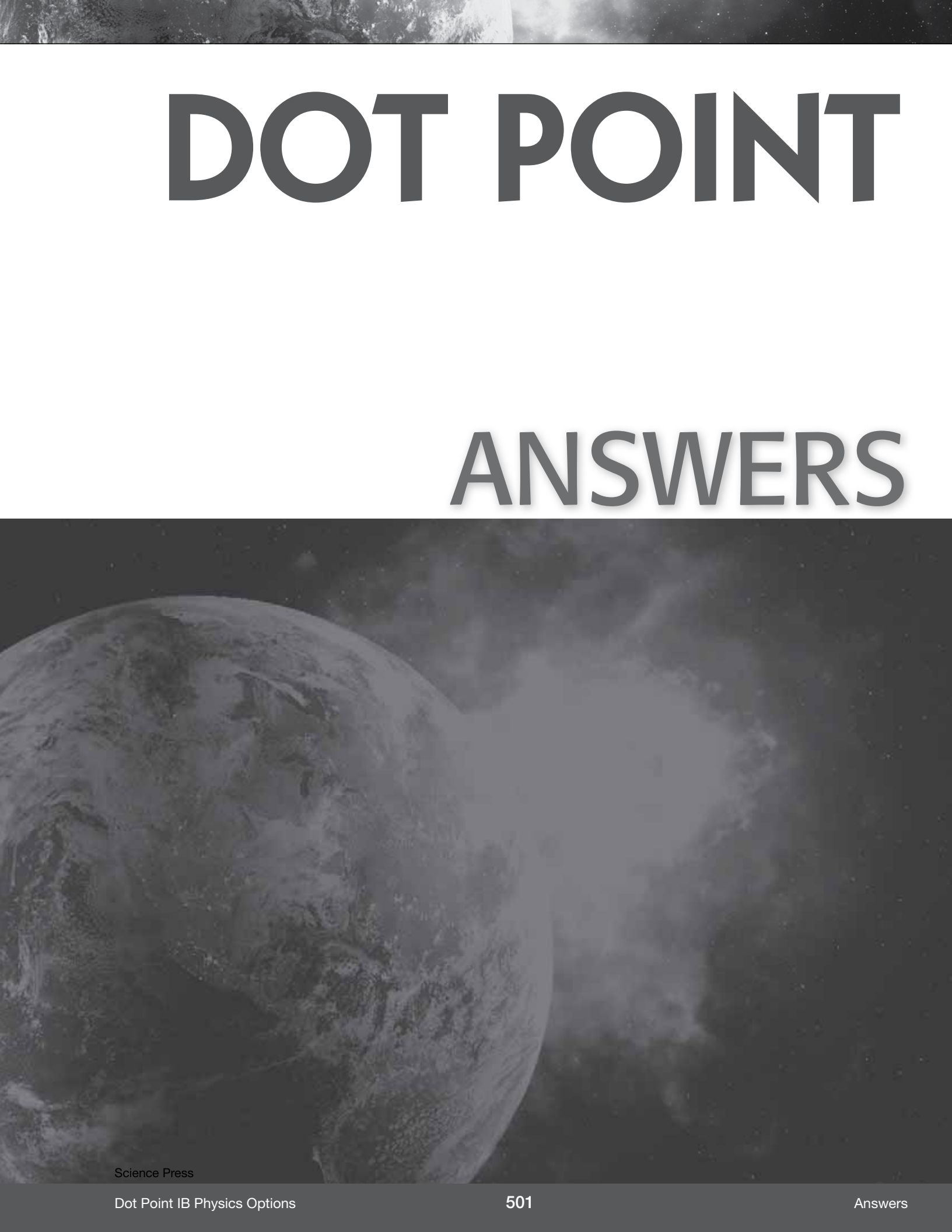


A.6.10.2 An unpolarised beam of light of intensity I_0 passes a polarising film whose plane of polarisation is 90° to the direction of the light beam. The intensity of the emerging light is:

- (A) Zero
- (B) $2I_0$
- (C) $I_0/2$
- (D) I_0

A.6.10.3 A polariser and analyser are positioned in the path of an unpolarised beam of intensity 5.00 W m^{-2} and the relative angles (angle between the polariser and analyser) are shown in the table. In each case estimate the intensity of light emerging from the analyser.

Relative angle	Intensity (W m^{-2})
0°	
90°	
75°	
60°	
45°	
30°	



DOT POINT

ANSWERS

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

OPTION A Sight and Wave Phenomena

A.1.1.1 A = pupil, B = iris, C = aqueous humour, D = lens, E = vitreous humour, F = retina, G = fovea, H = optic nerve, I = ciliary muscle.

A.1.1.2 The iris adjusts the amount of light entering the pupil, and the ciliary muscles adjust the shape and size of the lens causing the focal length to change.

A.1.1.3 Inverted, real, diminished.

A.1.1.4 Light follows this sequence from object to retina: Cornea, aqueous humour, lens, vitreous humour, retina.

A.1.1.5

Camera part	Aperture	Lens	Screen	Focusing system
Human eye part	Pupil	Lens	Retina	Ciliary muscles

A.1.2.1 B

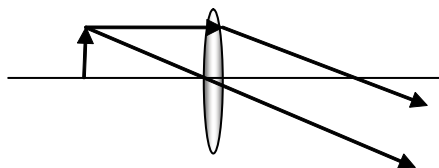
A.1.2.2 The near point is the nearest point at which the eye is able to focus without strain. When an object is situated at about the focal length of the human eye, it does not focus properly on the retina. This distance is called the near point.

A.1.2.3 The far point is the furthest distance from which an object can be brought into focus. This is infinity for a perfect eye.

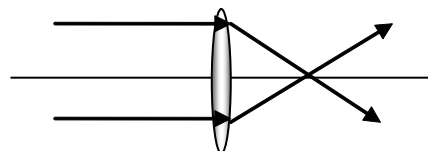
A.1.2.4 Accommodation is the ability of the eye to focus the image of an object. This is controlled by the ciliary muscles which adjust the shape of the lens making it smaller and rounder for the near point and less rounded for the far point.

A.1.2.5 C

A.1.2.6 (a) When an object is located near the focus, i.e. at the near point, the image is not focused at all.



(b) When an object is placed at the far point, the image is sharply focused at the retina and the ciliary muscles do not have to be overstressed.



A.1.2.7 Depth of vision is the ability to see in three dimensions.

A.1.2.8 Depth of vision is essential as it allows us to move around with a perception of three-dimensional space. Without it, we would fall or hit obstacles.

A.1.2.9 Methods include: Change in size of an approaching or retreating object; relative motion against a still background; comparing an unknown object's size with something of known size; stereoscopic triangulation (comparing the relative distance of both eyes); and inferences from memory.

A.1.2.10 B

A.1.2.11 C

A.1.2.12 Stereoscopic vision is the term used to describe the three-dimensional vision achieved by the human eye. It is achieved by the brain's interpretation of depth and distance by various methods such as viewing with two eyes focusing from two slightly different angles and distinguishing between colours, shades, size and clarity. The relative distance of an object to the two eyes plays the most important part in this vision.

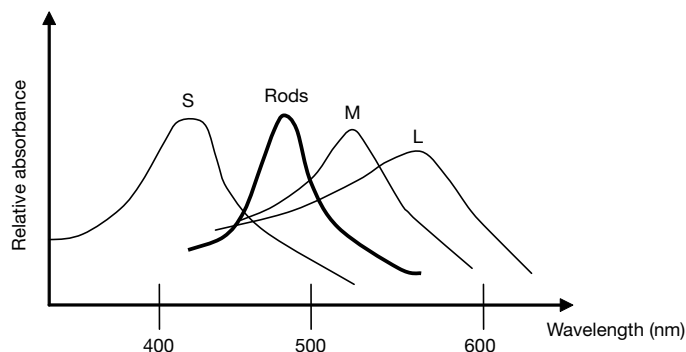
A.1.2.13 A

A.1.2.14 Corrective lenses can be used to bring the image forward or focus it further back.

A.1.2.15 B

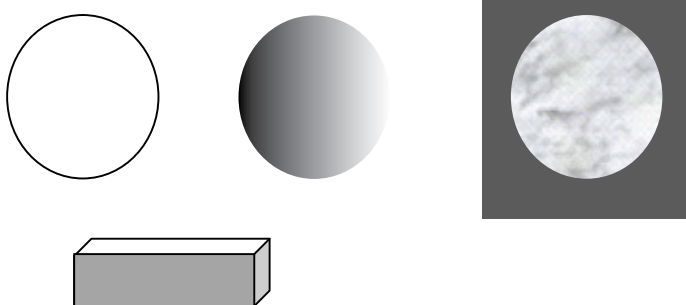
A.1.3.1 Both rods and cones are situated on the retina. However, rods are less common near the fovea and well distributed elsewhere; cones are concentrated in the fovea.

- A.1.3.2** A
- A.1.3.3** B
- A.1.3.4** Poor vision in dim light if an image is focused mainly on the fovea.
- A.1.3.5** D
- A.1.3.6** Cones are sensitive to red, green and blue. They are most sensitive to red and least sensitive to blue.
- A.1.3.7** B
- A.1.4.1** The ability to see in low light is called scotopic vision and the ability to see in normal light is called photopic vision.
- A.1.4.2** Rods have excellent sensitivity to low light conditions and are the main receptors in scotopic vision. Cones have significantly more sensitivity than rods under normal light and are the main receptors in photopic vision.
- A.1.4.3** The sensitivity of the eye to some wavelengths (colour) is reduced so that the cones do not record some colours. This causes colour blindness. For example, if red and green colours are not well perceived by a person, it could be due to the cones having diminished sensitivity to these colours.
- A.1.4.4**
- (a) Spectrum A is of rods and spectrum B is of cones. Rods have a higher sensitivity to shorter wavelengths and cones to longer wavelengths.
 - (b) Graph A is of scotopic vision as the rods are sensitive at shorter wavelengths and responsible for vision at low light intensities.
- A.1.4.5** At night, the chemicals in the eye responsible for processing images are synthesised slowly. Cones, which are the colour receptors, also have a slow response time. Rods, which are sensitive to low light and have a fast response time, are insensitive to colour. Therefore, as we try to decipher objects in colour, the overall response is slow.
- A.1.4.6** The point on the retina where the optic nerve leaves the eye has no rods or cones. Hence any image formed here is not registered by the eye and this spot is called the blind spot.
- A.1.4.7** D
- A.1.4.8**
- (a) Shown on graph.
 - (b) Shown on graph.



- (c) The monochromatic wavelengths corresponding to blue, green and red are not exactly 430 nm, 530 nm and 560 nm respectively, but a range of wavelengths. Hence it is more appropriate to call them short, medium and large.
 - (d) The person has got limited colour deciphering ability or colour blindness in the wavelengths showing low absorbance. The person has a lower response to colours peaking around 520 nm. This corresponds to the green colour. Hence the person will have red colour blindness.
- A.1.4.9** Rods are very sensitive to the blue region of the visible spectrum. Hence rods have significantly higher sensitivity at night.
- A.1.4.10** At night rods are the predominant receptors, not cones. Rods are not sensitive to colour hence night vision generally does not have clarity of colour.
- A.1.5.1** Colour addition: Light of certain wavelengths is added, e.g. red, green and blue emitting light together on a TV screen.
Colour subtraction: Light of a band of wavelengths is selectively absorbed, e.g. colour printing with cyan, magenta and yellow.
- A.1.5.2**
- (a) Yellow.
 - (b) White.
 - (c) Black.
- A.1.5.3** Primary colours are used to make up all of the other visible colours. Red, green and blue are primary colours of science and technology. The artist's primary colours are red, yellow and blue.

- A.1.5.4** In science, secondary colours are made by adding primary colours. For example, blue and green add up to make cyan; red and green make yellow; and red and blue make magenta.
- A.1.5.5** The wall absorbs all colours except the blue which is reflected. Hence the wall appears blue.
- A.1.5.6** The filter absorbed all colours except the red. Hence the transmitted light was red.
- A.1.5.7**
- (a) C1 is short, C2 is medium and C3 is long.
 - (b) The short cones C1 are most sensitive to blue which has the shortest of the three wavelengths, and the large cone is most sensitive to red C3 which has the longest of the three wavelengths. The middle cone C2 is also called green and is sensitive to green, i.e. the middle wavelength.
- A.1.5.8**
- (a) It is colour subtraction because colour is being subtracted (removed) from white light. It is also colour addition because the remaining colours (blue and green) add up to make yellow.
 - (b) The transmitted light is yellow. As blue is removed, red and green will remain which add up to yellow.
- A.1.5.9** C
- A.1.6.1** Relative size and clarity of different objects and backgrounds result in a perception of relative distance. Contours are interpreted from shadows, shape and colour contrasts. Stereoscopic vision, i.e. the relative distance of an object from the two eyes, also helps in deciphering relative distance.
- A.1.6.2**
- (a) Smaller: By painting the walls and ceiling with darker colours.
 - (b) Larger: By painting the walls and ceiling with lighter reflecting colours; and by placing mirrors in strategic locations to reflect light.
 - (c) Warmer: By using furniture in reddish colours and by painting the room in red-orange colours.
 - (d) Cooler: By painting the room in blue tones and by not overcrowding the room.
- A.1.6.3** Deep shadows from buildings are interpreted by our brain as coming from large buildings. Similarly our brains perceive smaller shadows as resulting from smaller buildings.
- A.1.6.4** Spatial depth may be realised by use of shading and contours as shown below.



- A.1.6.5** In drawing A there is an illusion of depth created by the lines becoming narrower and closer, i.e. a relative difference in size between objects perceived as further away as compared to those closer. In B, shades and relative differences in the background colour causes the brain to perceive contour and shade in the bars and circle.
- A.2.1.1** A travelling wave from one end interferes with the reflected wave setting up nodes and antinodes. The reflected wave, from a fixed end, is π degrees out of phase.
- A.2.1.2** A
- A.2.1.3** B, C and D.
- A.2.1.4** (a)

Maximum amplitude	20 cm
Wavelength	40 cm
Time period	0.001 s
A location which is a displacement node	P, S
A location which is a displacement antinode	Q, R, T
Two particles of the string which are in phase	Q and T, or P and S
Two particles of the string which are out of phase	P and Q or R and S

- (b) v refers to the speed of the two waves that travel in opposite directions at the same speed, with same wavelength and amplitude.

A.2.1.5 Energy provided by the oscillator, material and structure of the spring. When the initial and reflected waves are π degrees out of phase, maximum amplitude will result.

A.2.1.6 A wave starting from one end reflects from the other end either in phase (open end) or π degrees out of phase (closed end). The two waves then interfere with each other such that at points of nodes the net displacement of air molecules is zero and at points of antinodes, the displacement is most. Maximum amplitude, i.e. antinodes occur when the two waves are in phase and minimal (or zero) amplitude, i.e. nodes occur when the two waves are completely out of phase. The amplitude of the antinodal positions vary from zero to maximum with time.

A.2.1.7 When the forward and reflected waves add constructively to create a displacement antinode, the air molecules at that point are able to move the most hence creating a large amplitude. When the forward and reflected waves interfere destructively to form a node, the air molecules are compressed together and have the least amplitude of motion, hence have high pressure (pressure antinode) and zero displacement (displacement node).

A.2.3.1

	Statement	True or false?
(a)	In the fundamental standing wave, there is only one displacement antinode but two nodes.	T
(b)	Standing waves are created by two waves of the same frequency and wavelength travelling in opposite directions.	T
(c)	The fundamental standing wave is the loudest harmonic heard because the string vibrates with the highest amplitude.	T
(d)	Only the first two harmonics correspond to resonant frequencies; the other harmonics do not.	F
(e)	For a string of length L , the n th resonant frequency is given by $f_n = n \frac{v}{2L}$, where v is the speed of sound.	T
(f)	For a string of length L , the n th resonant frequency is given by $f_n = n \frac{v}{4L}$, where v is the speed of sound.	F
(g)	The third harmonic is a frequency three times that of the fundamental.	T
(h)	The third harmonic is a frequency two times that of the fundamental.	F
(i)	All harmonics, not just the even ones, are possible in a guitar string.	T
(j)	Only the odd number harmonics are possible in a guitar string.	F
(k)	A standing wave in a guitar string is set up due to the reflection from fixed ends, and this reflection is $\lambda/2$ out of phase with the incident wave.	T
(l)	The reflection from fixed ends in a guitar string are in phase with the incident wave thereby reinforcing the incident wave and causing resonance.	F
(m)	In the fundamental standing wave, there is only one pressure antinode but two nodes.	F

- A.2.3.2**
- (a) Soundwaves are reflected from open ends with a phase change of *half a wavelength*.
 - (b) At the ends of the flute there is a *destructive* interference and pressure *nodes*.
 - (c) The pressure of air is maximum *in the middle* of the flute and the pressure at the *ends* is equal to air pressure.
 - (d) The displacement of air molecules is *maximum* at the ends of the flute and for the fundamental, the displacement of air molecules is *minimum* in the middle of the flute.

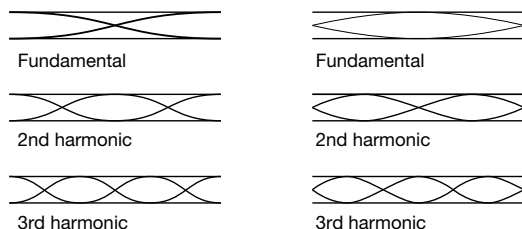
A.2.3.3

	Statement	True or false?
(a)	The harmonics are very similar to that of a string tied at both ends.	T
(b)	The harmonics are very similar to that of a string tied at one end and held loosely at the other end.	F
(c)	The motion of air particles is the least where there is a pressure antinode and most where there is a pressure node.	T
(d)	The motion of air particles is the least where there is a pressure node and most where there is a pressure antinode.	F
(e)	The frequency of the third harmonic is three times that of the fundamental.	T
(f)	The frequency of the third harmonic is 2/3 times that of the second harmonic.	T

A.2.3.4

(a) Displacement modes.

(b) Pressure modes.


A.2.3.5

- (a) Soundwaves are reflected from the closed end of the air column with a change of phase = π . Therefore there is *constructive* interference at the closed end and a pressure *node* results.
- (b) The fundamental mode of vibration will have the relationship $L = \frac{\lambda}{4}$ where L is the length of the air column. Only *odd* number of harmonics are possible.

A.2.3.6

An air column above water is like a pipe closed at one end. The resonant frequencies follow the relationship $f_n = nv/4L$, where $n = 1, 3, 5, 7 \dots$. As water is filled in, the length of air column, L , reduces thereby increasing the frequency.

A.2.3.7

(a) String fixed at both ends:

It can be shown that the harmonics are $L_1 = \frac{\lambda}{2}$, $L_2 = \frac{2\lambda}{2}$, $L_3 = \frac{3\lambda}{2}$, ... $L_n = \frac{n\lambda}{2}$ corresponding to $f_n = \frac{nv}{2L}$.

(b) Pipe closed at one end: It can be shown that the harmonics are $L_1 = \frac{\lambda}{4}$, $L_3 = \frac{3\lambda}{4}$, $L_5 = \frac{5\lambda}{4}$...

Only the odd harmonics are possible.

Thus, $L_n = \frac{n\lambda}{4}$, where n is an odd number.

The relationship corresponds to $f_n = \frac{nv}{4L}$, where n is an odd number.

(c) Pipe open at both ends: Same as string fixed at both ends.

A.2.3.8

Using $f_n = \frac{nv}{2L}$ and $L_n = \frac{n\lambda}{2}$ for pipes open at both ends and for strings, and $f_n = \frac{nv}{4L}$ and $L_n = \frac{n\lambda}{4}$ for pipes closed at one end, the following results are obtained.

Ratio of:	Ratio is:
Fundamental frequency to the 3rd harmonic for a string	1:3
2nd harmonic frequency to the 4th harmonic for a string	1:2
2nd harmonic frequency to the 3rd harmonic for a pipe open at both ends	2:3
The wavelength of the fundamental to the 3rd harmonic for a string	3:1
Fundamental frequency to the next higher frequency for a pipe closed at one end	1:3
The wavelength of the 2nd harmonic to the 4th harmonic for a pipe open at both ends	2:1

A.2.3.9

$$L = \frac{v}{4f} = \frac{815}{4 \times 312} = 0.65 \text{ m}$$

A.2.3.10

End correction is $0.4d = 0.4 \times 0.2 = 0.08 \text{ m}$. We would need to add this value to the calculated wavelength.

A.2.4.1

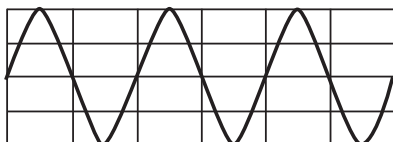
The energy of the oscillator is transmitted from one end of the medium through to the other in a travelling wave. However, this energy changes the amplitude of the standing wave and is not transmitted from one end to the other in a standing wave.

A.2.4.2

Amplitude is the same for all string elements in a travelling sinusoidal wave. In a standing wave, amplitude varies with position along the string. The positions of node have zero amplitude while positions of antinode have amplitude which oscillates from zero to maximum.

- A.2.4.3** A travelling (sinusoidal) wave of uniform speed can be represented as a graph of amplitude versus distance or amplitude versus time. Measurement of wavelength and time periods can be obtained as distance or time for one wave cycle, as shown.

Travelling wave:



Standing wave:

$$t = t_0$$



$$t = T/2$$



← Wavelength →

A standing wave can also be represented as sine curves showing the wave at both extremes of their oscillation. The time period can be obtained by graphing successive movements of the antinodal points and noting the time it takes to return to its original position. The distance between nodes is half a wavelength, and so is the distance between antinodes. Hence the wavelength is the distance between two nodes or two antinodes.

- A.2.4.4** The different elements of the string of a travelling wave are in a variety of phases, i.e. the phase difference between different parts of the string varies between 0 and 2π . However, when a standing wave is set up in a string, the elements are either in phase or out of phase by π or 2π .

- A.2.5.1** Frequency will be 10 Hz as it passes through the mean position twice as it completes one full oscillation. Hence the time period will be 0.01 s.

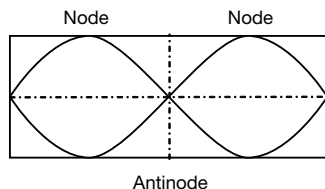
A.2.5.2

Information	Wavelength (m)
Distance between the 1st node and 2nd node is 0.4 m	0.8 m
Distance between the 1st node and 3rd antinode is 0.6 m	0.48 m
Distance between the 1st antinode and 2nd node is 0.3 m	1.2 m

- A.2.5.3**
- The location of the nodes and antinodes does not change with time.
 - Compression waves from each identical tuning fork travel towards each other with the same speed, wavelength and frequency. The two waves interfere constructively and destructively causing antinodes and nodes thereby setting up a standing wave.
 - Speed of sound = $f \times \lambda = f \times 2L = 337.8 \text{ m s}^{-1}$.

- A.2.5.4**
- $v = 2L \times f_0 = 2 \times 0.5 \times 512 = 512 \text{ m s}^{-1}$.
 - $f_4 = 4 \times f_0 = 4 \times 512 = 2048 \text{ Hz}$.
 - The length will be shortened for the 2nd harmonic which is $= 2 \times f_0 = 2 \times 512 = 1026 \text{ Hz} = 512/2L$. Therefore $L = 0.25 \text{ m}$. This is consistent in practice when shortening a guitar string with a finger produces a higher frequency.

- A.2.5.5**
- (a) (i) Wavelength of the fundamental = $2L = 2 \times 0.25 = 0.5$ m. The fundamental frequency is $340/0.5 = 680$ Hz.
(ii) Frequency of the 3rd harmonic is $3 \times 680 = 2040$ Hz.
(iii) Wavelength of the 4th harmonic = $v/f_4 = 340/(4 \times 680) = 0.125$ m.
- (b) A sketch is shown on the figure for the 2nd harmonic.



- A.2.5.6**
- (a) $v = f \times \lambda = v \times 4L = 467.2 \times 4 \times 0.166 = 310.2 \text{ m s}^{-1}$
(b) The next harmonic is $3 \times 467.2 = 1401.5$ Hz
(c) When water is drained off, new $L = 0.3$ m. New $f_0 = 310.2/(4 \times 0.3) = 258.5$ Hz

- A.2.5.7**
- (a) $f = v/2L = 345/(2 \times 0.5) = 345$ Hz
 $f_2 = 690$ Hz
 $f_3 = 1035$ Hz
- (b) If the bottom end is closed, then the even harmonics will *not* be present. Peaks corresponding to f_2 and f_4 will *not* be present. The fundamental frequency also changes.

A.2.5.8

$$f = \frac{1}{2L} \sqrt{\frac{T}{M}} = \frac{1}{2 \times 0.3} \sqrt{\frac{60}{0.00267}} = 250 \text{ Hz}$$

- A.2.5.9**
- (i) Speed, $v = \sqrt{\frac{T}{M}} = \sqrt{\frac{100}{5 \times 10^{-3}}} = 141.4 \text{ m s}^{-1}$.
(ii) Wavelength = $2L/3 = 0.4$ m.
(iii) Frequency = $v/\lambda = 141.4/0.4 = 353.5$ Hz.

- A.3.1.1**
- (a) As the police car approaches you, the frequency will rise and as the police car goes away, the frequency will reduce.
(b) As the police car approaches you, the soundwaves coming to you are closer together, i.e. have a lower wavelength and therefore a higher frequency. As the police car goes away, the waves are further apart, and therefore have a lower frequency. The speed of sound is the same as the medium is unchanged.

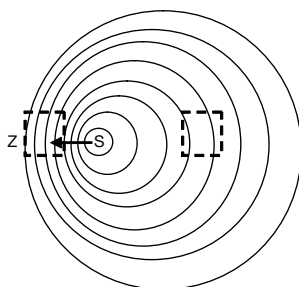
- A.3.1.2**
- (a) Figure B represents the source moving towards the observer, as the waves are closer together towards the observer.
(b) The Doppler effect is for relative motion, so a source moving towards the observer would result in the same effect as the observer moving towards the source. Hence Figure A could also represent the observer moving away from the source.

- A.3.1.3**
- (a) $f' = f/(1 \pm v_s/v) = f/((v \pm v_s)/v) = f(v/(v \pm v_s))$
(b) The wavelength seen by both is the same:
 $\lambda = (v \pm v_o)/f_o = (v \pm v_o)/f_s$; $f_s = f_o((v \pm v_o)/(v \pm v_s))$
(c) If the observer is stationary and the source moves towards the observer, then v_s is negative and the frequency observed is higher. However, if the source moves away, then v_s is positive and the observed $f' < f$ frequency appears reduced. Similarly, if the source is stationary and the observer moves towards the source, then v_o is positive and $f' > f$.

A.3.1.4

Observer	Source	Change in observed frequency
Moving towards the source	Stationary	$f' > f$
Moving away from source	Stationary	$f' < f$
Stationary	Moving away	$f' < f$
Stationary	Moving towards	$f' > f$
Moving towards source	Moving towards observer	$f' > f$
Moving away from source	Moving away from observer	$f' < f$

- A.3.1.5** As the source moves towards the observer at point Z, there will be less distance for the same number of waves to exist in a given time period (see box). Hence the wavelength will be reduced and frequency will be higher, i.e. the source catches up with its own soundwaves.



- A.3.3.1** (a) Using $f' = f \left[\frac{v}{v - v_s} \right]$ and converting speed to m/s, $f' = 1108.7$ Hz.

- (b) Using $f' = f \left[\frac{v}{v + v_s} \right]$ and converting speed to m/s, $f' = 910.7$ Hz.

- A.3.3.2** Using $f' = f \left[\frac{v}{v - v_s} \right]$ and $f' = f \left[\frac{v}{v + v_s} \right]$ two simultaneous equations are developed.

$$1400 = f \left[\frac{340}{340 \pm v_s} \right] \text{ which when solved give (a) } v_s = 26.15 \text{ m s}^{-1} \text{ (94 kph) and (b) } f = 1292.3 \text{ Hz.}$$

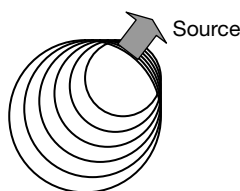
- A.3.3.3** (a) Using $f' = f \left[\frac{v}{v - v_s} \right]$, $850 = 800 \left[\frac{340}{340 - v_s} \right]$, $v_s = 20 \text{ m s}^{-1}$.

- (b) $f' = f \left[\frac{v}{v + v_s} \right]$, $f' = 800 \left[\frac{340}{340 + 20} \right] = 756.6$ Hz.

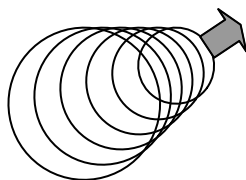
- (c) Wavelength = speed/frequency = $340/850$ and $340/756.6 = 0.4 \text{ m}$ and 0.45 m respectively for (a) and (b).

- (d) Wavelength = speed/frequency = $340/800 = 0.425 \text{ m}$.

- A.3.3.4** (a) Since the wavefronts ahead of the source are close together and travelling at the speed of sound, all of the compressed wavefronts and the source arrive to the observer at the same time. This causes the loud sound and the front is a region of immense air pressure resulting in turbulence by the plane.



- (b) This is supersonic travel. The source is now travelling faster than the sonic cone of compressed waves it produces which travels at the speed of sound. The two loud sounds are from the front and the tail of the plane. The wavefronts from the tail are shown in the figure.



- A.3.5.1** The wavelength is blue-shifted so the galaxy is seemingly moving away from us.

- A.3.5.2** (a) Using $f' - f = \Delta f = \frac{v}{c} f$, $f' = 1.65 \times 10^9$ Hz. Frequency will be higher by Δf .

- (b) Using $f - f' = \Delta f = \frac{v}{c} f$, $f' = 1.41 \times 10^9$ Hz. Frequency will be lower by Δf .

- A.3.5.3** (a) As the frequency increases, the galaxy is moving towards the Earth. However, it should be noted that as the Universe expands, galaxies would be found to be mostly moving away from Earth.

- (b) Using $\Delta f = \frac{v}{c} f$, $0.15 \times 10^{12} = \frac{v}{3 \times 10^8} \times 2 \times 10^{12}$, $\therefore v = 0.225 \times 10^8 \text{ m s}^{-1}$.

- A.3.5.4** (a) $f' = f \left[\frac{1}{1 \pm \frac{v_s}{v}} \right]$ and $c = f\lambda$. Now substitute $\lambda = c/f$ and $\lambda' = c/f'$ to obtain $\lambda' = \lambda \left(\frac{v \pm v_s}{v} \right)$.
- (b) If the source is moving away from Earth the wavelength as seen by us is longer and the colour is shifted towards red – hence this is called the red-shift. If the source is moving towards us, then the colour of the emitted radiation shifts towards the blue. Generally galaxies show red-shift, proving that the Universe is expanding.

- A.3.5.5** (a) $f = \frac{c}{\lambda} = \frac{3 \times 10^8}{520 \times 10^{-9}} = 5.77 \times 10^{14} \text{ Hz}$.
- Therefore, $\Delta f = \frac{v}{c} f = 0.01 \times 5.77 \times 10^{14} \text{ Hz}$ and $f' = 5.71 \times 10^{14} \text{ Hz}$. Therefore $\lambda = \frac{c}{f} = \frac{3 \times 10^8}{5.71 \times 10^{14}} = 525.3 \text{ nm}$.
- (b) $\lambda_0 = \lambda_s \left((1 + v_s/c) = 520(1 + (0.01c/c)) = 525.2 \text{ nm}$.
- (c) The red-shift will be $525.2 \text{ nm} - 520 \text{ nm} = 5.2 \text{ nm}$. This tells us that the galaxy is moving away and the Universe is expanding. Measurement of the red-shift over time also tells us that the Universe is expanding at an accelerating rate.

- A.3.6.1** Use $f' = f \left[\frac{v}{v - v_s} \right]$, where v = speed of sound and v_s is the speed of the source.

$$f' = f \left[\frac{v}{v - v_s} \right], \therefore 1045 = 1000 \left[\frac{v}{v - 15} \right], v = 348.3 \text{ m s}^{-1}.$$

- A.3.6.2** (a) When the police car sends out the signal to the moving car, it is a case of a stationary source with the object moving towards the source.

$$\text{Hence } f'_1 = f \left(1 + \frac{v_{\text{car}}}{v_{\text{sound}}} \right) \text{ or } f'_1 - f = f \left(\frac{v_{\text{car}}}{v_{\text{wave}}} \right).$$

The soundwave then reflects back from the car which then behaves as the new emitter travelling towards the observer, i.e. source moving towards the object.

$$\text{Hence } f'_2 = f'_1 \left[\frac{1}{1 - \frac{v_{\text{car}}}{v_{\text{wave}}}} \right].$$

$$\text{Simplifying this would give } \Delta f = \frac{2fv_{\text{car}}}{v_{\text{wave}}}.$$

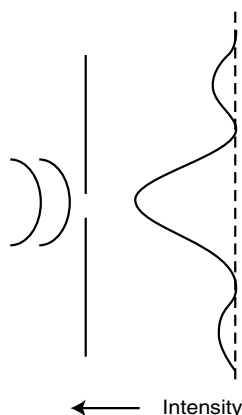
- (b) Use $\Delta f = (24 - 19.7) \times 10^9 = 4.3 \times 10^9 = \frac{2fv}{v_{\text{wave}}} = \frac{2 \times 24 \times 10^9 \times v}{340}$, $\therefore v = 30.46 \text{ m s}^{-1}$.

- A.3.6.3** (a) $\Delta f = \frac{2fv_{\text{blood}}}{v_{\text{sound, blood}}} = \frac{2 \times 3 \times 15}{1480} = 0.06 \text{ MHz}$. Therefore $f' = 3.06 \text{ MHz}$ (or 2.94 MHz if blood is moving away).

- (b) $\Delta f = \frac{2fv_{\text{blood}}}{v_{\text{sound, blood}}} = 0.12 = \frac{2 \times 3 \times v}{1480}$. $\therefore v = 29.6 \text{ m s}^{-1}$.

The higher speed could mean that the artery is constricted perhaps due to fatty deposits (cholesterol).

A.4.1.1



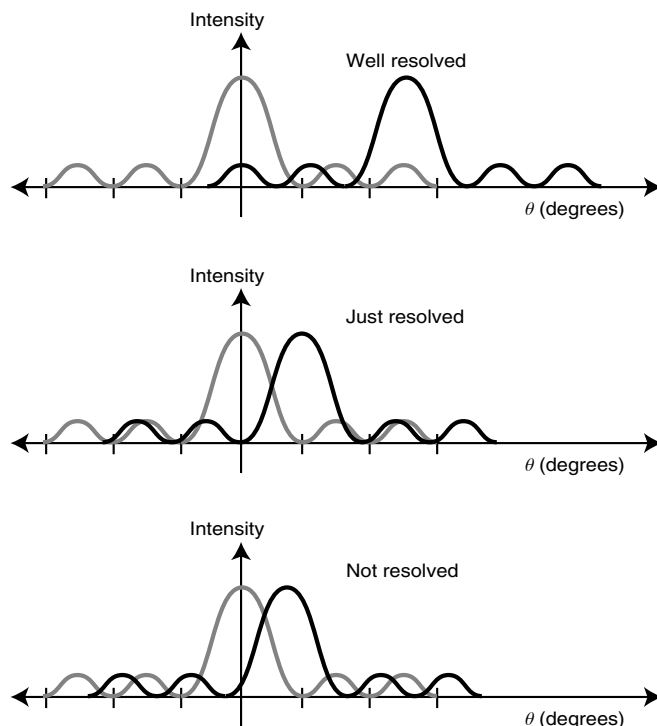
- A.4.1.2** Each point in the slit acts as a source of secondary wavelets (Huygens principle) which interfere to form regions of constructive and destructive interference, which is a diffraction pattern.

- A.4.1.3** (a) Wavelets arrive at points from all positions along the slit. However, wavelets from one side of the slit will be out of phase to varying degrees except at the centre. The further one is from one side the more waves that are out of phase and the less the intensity of the maximum.
- (b) The central maximum is wider ($\times 2$) and more intense than the other fringes as wavelets from all parts of the slit arrive in phase.

- A.4.2.1**
- (a) Path difference for the first minimum = 0.5λ . Waves from a pair of Fresnel points arrive at the first minimum with a phase difference of π and a path difference of 0.5λ and undergo completely destructive interference.
- (b) For small angles, path difference = $b \sin \theta$. Whenever the path difference is $n\lambda$, destructive interference occurs.
Thus, for the first minimum $\sin \theta = \frac{\lambda}{b}$. For small angles, $\sin \theta \approx \theta = \frac{\lambda}{b}$.
- (c) $b \sin \theta = n\lambda$, $n = 1, 2, 3, \dots$
- (d) $b \sin \theta = (n + \frac{1}{2})\lambda$, $n = 1, 2, 3, \dots$
- A.4.2.2**
- (a) For small angles, $\sin \theta \approx \tan \theta = \lambda/b$.
 $\tan \theta = \sin \theta = x/L$ for 1st order dark fringe.
 For second order dark fringe, $\sin \theta = 2\lambda/b$ and similarly for the n th order dark fringe $\sin \theta = n\lambda/b$.
 Therefore $\frac{n\lambda}{b} = \frac{x}{L}$.
 An alternative reasoning could be that for the 1st order dark band, $\frac{b}{2} \sin \theta = \frac{\lambda}{2}$.
 Therefore $\sin \theta = \lambda/b$.
- (b) For constructive interference, $\sin \theta = 1.5\lambda/b$ when $n = 1$; 2.5λ when $n = 2$ and similarly for the n th order $\frac{(n + \frac{1}{2})\lambda}{b} = \frac{x}{L}$.
- (c) (i) For the 1st minimum, $\sin \theta = \lambda/b$, $\theta = \sin^{-1} \frac{500 \times 10^{-9}}{1 \times 10^{-5}} = 2.86^\circ$.
 (ii) Similarly, for the 3rd minimum, $\theta = 8.63^\circ$.
- A.4.2.3**
- (a) For the second order bright fringe, $\frac{(n + \frac{1}{2})\lambda}{b} = \frac{x}{L}$ and $n = \frac{(2 + \frac{1}{2})500 \times 10^{-9}}{0.09 \times 10^{-3}} = \frac{x}{2.5}$, $x = 3.47 \text{ cm}$.
- (b) The thickness of the central maximum is $2 \times$ distance from centre of central maximum to the centre of the first dark band
 $= 2 L \lambda/b = \frac{2 \times 2.5 \times 500 \times 10^{-9}}{0.09 \times 10^{-3}} = 2.7 \times 10^{-3} \text{ m} = 2.7 \text{ mm}$.
- (c) For the first dark band, $\sin \theta = \lambda/b = \frac{500 \times 10^{-9}}{0.09 \times 10^{-3}}$. Therefore $\theta = 0.32$ degrees.
 Therefore, the width of the central maximum is 0.64 degrees.
- A.4.2.4** $b \sin \theta = m\lambda$, $b = \frac{m\lambda}{\sin \theta} = \frac{520}{\sin 10} = 2994.6 \text{ nm} \approx 3 \text{ } \mu\text{m}$.
- A.4.2.5** $\lambda = \frac{b \sin \theta}{m} = \frac{2 \sin 15}{1} = 0.52 \text{ } \mu\text{m}$.
- A.4.2.6** The first maximum is between the 1st and the 2nd minima. A value of 1.5 for m could be used. $\lambda = \frac{b \sin \theta}{m} = \frac{2 \sin 18}{1.5} = 0.41 \text{ } \mu\text{m}$.
- A.4.2.7** $\theta = \sin^{-1} \left[1.22 \frac{\lambda}{d} \right] = 34^\circ$
- A.5.1.1** Resolution is the property of the lens which describes how well the lens is able to produce two distinct images of two point sources very close to one another.
- A.5.1.2** A better resolution exists in a system where the point sources are closer together while still imaging distinctly. That is why resolution is measured in lines/mm.
- A.5.1.3** One factor is lens aberration in which point objects image as fuzzy objects. The other factor is diffraction which is not due to the lens but due to the wave-like nature of light. Diffraction causes bending and interference.
- A.5.1.4** A bright central circular image followed by rings of reducing intensity.

A.5.1.5

The distinct diffraction patterns of two sources will eventually overlap becoming one. An example of diffraction intensity versus distance is shown. As objects are brought closer together they lose resolution.



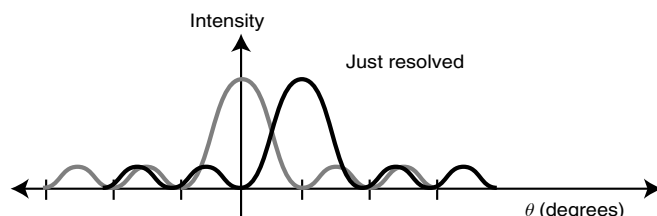
A.5.2.1

For small angles $\sin \theta \approx \theta = \tan \theta$ and the width equivalent for circular aperture is $b = a/1.22$.

Hence $\sin \theta = \frac{\lambda}{a}$ gives angular position of the first minimum for a rectangular slit and $\theta = 1.22 \frac{\lambda}{b}$ is the angular position of the first minimum in a circular aperture.

A.5.2.2

The Rayleigh criterion states that the two images from two point sources will be just resolved if the peak of the central maximum of one just overlaps the first minimum of the other.



A.5.2.3

For higher resolution use larger apertures and smaller wavelength. Hence techniques with smaller wavelength, such as electron microscopy, give better resolution. Radio waves with astronomical telescopes require much larger apertures.

A.5.2.4

- For small angles, we can use $\sin \theta \approx \tan \theta$. Therefore, $s = f\theta = 1.22 \frac{f\lambda}{b}$.
- Red light has a lower wavelength so would give a lower value of resolving power, hence better resolution.
- As $f \approx b$, $s = f\theta = 1.22 \frac{f\lambda}{b} = 1.22 \frac{b\lambda}{2b} \approx \frac{\lambda}{2}$, where b = aperture.

A.5.2.5

The patterns would be those of completely resolved and unresolved patterns shown in A.5.1.5.

A.5.4.1

- Using $\theta = 1.22 \frac{\lambda}{b} = 1.22 \times \frac{680 \times 10^{-9}}{40 \times 10^{-3}} = 20.7 \mu\text{rad}$.
- Blue light has a smaller wavelength and hence would give a smaller θ , which means better resolution.

A.5.4.2

- $\theta = 1.22 \frac{\lambda}{b} = 1.22 \times \frac{600 \times 10^{-9}}{50 \times 10^{-3}} = 14.6 \mu\text{rad}$.
- $s = r\theta = 10\,000 \times 14.6 \mu\text{rad} = 0.15 \text{ km}$.
- $s = r\theta = 1.22 \frac{r\lambda}{b} = 1.22 \times \frac{1000 \times 600 \times 10^{-9}}{50 \times 10^{-3}} = 0.015 \text{ m}$.

- A.5.4.3** (a) $\theta = 1.22 \frac{\lambda}{b} = 1.22 \times \frac{600 \times 10^{-9}}{4} = 183 \text{ nanoradians.}$
 (b) $\theta = 1.22 \frac{\lambda}{b} = 1.22 \times \frac{0.05}{4} = 0.015 \text{ rad.}$
 (c) Take a larger objective, e.g. 100 m.

A.5.4.4 $\theta = 1.22 \frac{\lambda}{b} = 1.22 \times \frac{570 \times 10^{-9}}{2.1 \times 10^{-3}} = 330 \text{ } \mu\text{rad.}$

Further, $r = s/\theta = (1.8/330) \times 1\,000\,000 = 5.4 \text{ km.}$ Clearly we may have vision that far, and other factors such as pollution and intensity will factor in the actual observation.

A.5.4.5 The role of resolution in the development of electron microscopes, and also DVDs and CDs, is fascinating but quite complex and you are urged to research this from reliable sources. The small wavelength used in electron microscope is the key to higher resolution. These electrons can have a wavelength of $< 10^{-11} \text{ nm}$, which is less than that of interatomic separation. While scanning electron microscopes (SEMs) can resolve a fraction of a micron, transmission electron microscopes (TEMs) can resolve in tens of nm. SEMs are typically used to study surface structures, and TEMs for atomic structure.

A.5.4.6 Using $s = r\theta$, $\therefore r = \frac{s \times b}{1.22\lambda} = \frac{5 \times 1.8 \times 10^{-3}}{1.22 \times 600 \times 10^{-9}} = 12.5 \text{ km.}$

A.6.1.1 An electromagnetic wave consists of an oscillating electric and magnetic field at right angles to each other. A light wave is plane polarised when all components of the electric field, except in one plane, are blocked.

- A.6.1.2** (a) B and C.
 (b) B and C.
 (c) A and D. The vibration modes are in two different directions.

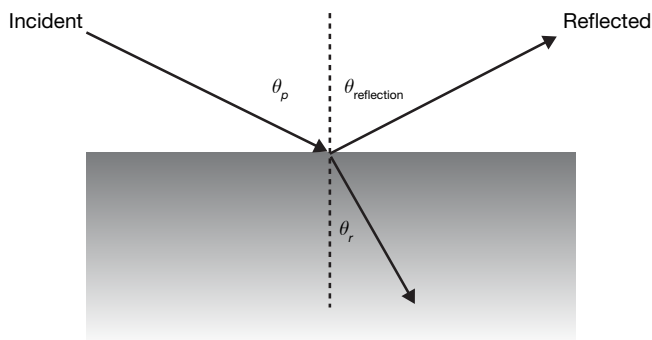
A.6.1.3 In unpolarised light, there are many electric field vectors always at right angles to the direction of wave propagation. In plane polarised light, there is only one plane of the electric field vector as dictated by the polarising sheet.

A.6.2.1 When light waves meet the surface of water, waves and wave components that are vertical to the surface are able to pass into the water. However, waves and wave components that are parallel to the surface are reflected as polarised light.

A.6.2.2 Light reflected from surfaces such as water, ice and snow are plane polarised parallel to that surface. Sunglasses are made with vertically plane polarised material so that the intense reflected light from water, ice or snow is not transmitted to the eye.

A.6.2.3 Light, other than at right angles to a surface, is reflected largely as plane polarised. The angle at which this polarisation is maximum (nearly 100%) is called the polarising angle θ_p , which is also called Brewster's angle. This is given by $\tan \theta_p = \frac{n_{\text{water}}}{n_{\text{air}}}$, where n_{water} is the refractive index of water and n_{air} is the refractive index of air.

A.6.2.4 When the incident ray strikes the surface at Brewster's angle the reflected and refracted rays are at right angles to each other, i.e. angle $\theta_p + \text{angle } r = 90^\circ$.

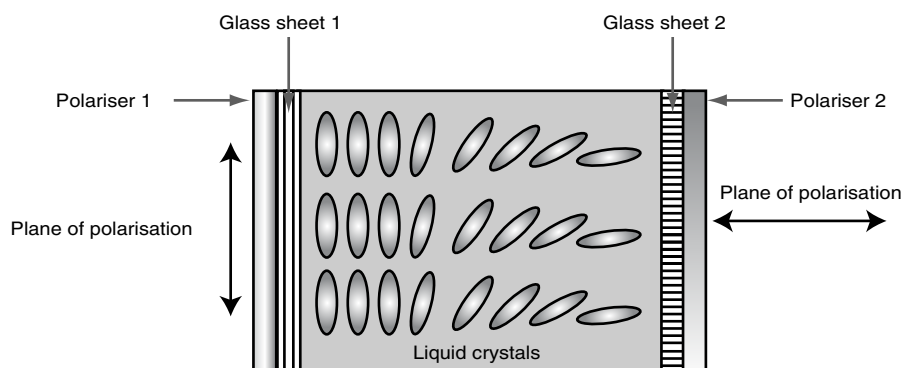


A.6.2.5 This is a fairly complex matter. Briefly, when unpolarised light strikes a diamond face cut at Brewster's angle (about 67.5°), the reflected ray is plane polarised and the transmitted light is at 90° to this. When the light ray from inside the diamond strikes the diamond-air interface to transmit out, it will strike at angles greater than the critical angle (24.5°) so that it reflects back into the diamond as plane polarised light. This further splits the light into its wavelengths giving a glittering appearance. A light beam would make several reflections within the diamond while it continues to separate into colours as well before it transmits out of the diamond, thereby giving the glittering look.

- A.6.2.6** (a) Using $\tan \theta_p = \frac{n_{\text{ethanol}}}{n_{\text{air}}}$, $\theta_p = 55.6^\circ$.
 (b) Using Snell's law, $n_{\text{ethanol}} = \frac{\sin \theta_{\text{air}}}{\sin \theta_{\text{ethanol}}}$, $\therefore \theta_{\text{ethanol}} = 34.4^\circ$.
 (c) The angle of reflection is equal to the angle of incidence = 55.6° . As a check, angle of reflection + angle of refraction is 90° , when the incident angle is the Brewster's angle.

- A.6.4.1** A polariser is the device which allows electromagnetic waves in one plane to get through it. Polaroid is the name given to the materials (or a brand name) which can polarise, e.g. the mineral tourmaline or synthetic chemicals.
- An analyser is also a polaroid material which is placed in the path of a plane polarised light for analysis of certain properties or for blocking all electromagnetic waves.
- A.6.4.2** If the planes of the analyser and polariser are at right angles, then no light would come through.
- A.6.4.3** Light is a transverse wave similar in this respect to the transverse motion in a rope. Those waves parallel to a slit would get through while those at other angles would have only the appropriate component (parallel to the slit) that would get through. If the wave is at right angles to the slit, no wave would be transmitted to the other side of the slit.
- A.6.4.4**
- Since both directions are vertical, the plane polarised light from the first sheet (polariser) will pass entirely through the second sheet (the analyser).
 - Sheet 1 (polariser) will polarise light in the vertical direction and sheet 2 will block the light (analyser).
 - Sheet 1 (polariser) will polarise light in a vertical direction and sheet 2 (analyser) will transmit some of the light in accordance with Malus' law discussed in the next section.
- A.6.5.1** Only the component of electric field in the direction of the polarisation axis would be transmitted. This component is $E = E_0 \cos \theta$. Intensity of an electromagnetic wave is proportional to the square of the amplitude of an electromagnetic wave. Hence $I = I_0 \cos^2 \theta$.
- A.6.5.2** $I/I_0 = \cos^2 \theta = 0.8$
- A.6.5.3**
- Unpolarised light can be resolved into two mutually perpendicular planes, one of which is the direction of the polariser's axis. The intensity of the polarised light will be half that of the incident light = 5.0 W m^{-2} due to polarisation of one component.
 - $I = I_0 \cos^2 \theta = 10 \times \cos^2 70 = 1.17 \text{ W m}^{-2}$.
 - The axis of the two polarisers should be at 90° to each other hence the second polariser needs to be turned a further 20° .
 - The axis of the two polarisers should be at 0° to each other hence the second polariser needs to be turned back 30° or turned a further 110° .
- A.6.5.4** An optically active substance is one which rotates the plane of polarisation of a polarised light. Examples are stressed glasses and plastics. Sugars, quartz, calcite and turpentine are also optically active.
- A.6.5.5**
- The incident light vector (E) can be resolved in directions parallel to and perpendicular to the polarising direction of sheet 1. Hence all light components parallel to the polarising direction of the sheet will emerge and one perpendicular to it will not. Hence the intensity of emerging light will be $I_0/2$. The light will be plane polarised at right angles to the direction of travel of incident light.
 - The light emerging from sheet 1 is the incident light on sheet 2. Applying the cosine squared rule, intensity emerging from the second sheet will be $= I_0/2 \times \cos^2 45^\circ = 0.25 I_0$. The light will be plane polarised at 135° (or 45°) to the incident light.
 - The light emerging from sheet 2 is the incident light on sheet 3. Applying the cosine squared rule, intensity emerging from the second sheet will be $= 0.25 I_0 \times \cos^2 45^\circ = 0.125 I_0$. The light will be plane polarised at 45° to the second sheet which is parallel to the direction of travel of incident light.
- A.6.7.1** A sample of blood is treated to remove cells and retrieve the plasma. It is placed between two sheets of polarising material, namely the polariser and the analyser, the latter being crossed with respect to the polariser. No light is expected to come through. However, because the sugar in the serum rotates the plane of light, some intensity does come through. The analyser is then rotated carefully until no light emerges. The rotation angle is then a measure of concentration of sugar. Of course, the process will need to be standardised with known concentrations, set temperatures, certain wavelengths of light and fixed distances.
- A.6.7.2**
- The technique can be employed with any solution containing dextrose (sugar) such as fruit juice, alcohol and blood.
 - Some substances such as sugar rotates the polarisation vector clockwise and the specific rotation angle is labelled positive, while others like nicotine rotate counterclockwise and their specific rotation angle is negative.
 - Both temperature and wavelength affect how much the sugar solution can rotate the plane of polarised light, hence both must be standardised. For example, measurements could be reported at 20°C , 589 nm of Na-D line and a 0.1 g/100 mL concentration.
 - A
- A.6.7.3** The stressed plastic or glass piece is placed between a polariser and an analyser, the latter being crossed. The stresses cause bands to occur in the plastic or glass which are an indication of stress.
- A.6.7.4** Using $L = 0.2 \text{ dm}$, and $r_{\text{specific}} = \frac{r_{\text{rotation}}}{L \times C}$ and noting that L is in dm, C in g/mL, we get $r_{\text{rotation}} = 1.2^\circ$.
- Errors include correlation between different units and values such as specific rotation angle, errors in standardisations and errors in measurements.

- A.6.7.5** B
- A.6.7.6** C
- A.6.7.7** Calculators, timers, thermometers, digital watches, several types of meters including ammeters and voltmeters, projection systems including TV.
- A.6.7.8** Pixel stands for picture elements. These rectangular components make up the LCD.
- A.6.7.9** Liquid crystals are polar-active, highly viscous polar organic compounds with one-dimensional orderliness of crystals while still possessing the randomness of liquids.
- A.6.7.10** Glass plates, holding the liquid crystals, are etched with parallel lines in which direction the liquid crystals orientate. One plate typically has lines at right angles to the other.
- A.6.7.11** Glass plate 1 with vertical scratches has a polariser on the outside with a vertical plane of polarisation. Glass plate 2 with horizontal scratches has a polariser on the outside with a horizontal plane of polarisation. Between the two plates, the liquid crystal molecules line up from vertical to horizontal in a twisted pattern.



- A.6.7.12** With no voltage, light polarised on entry passes through the LCD as the liquid crystal rotates the plane of polarised light so that it can pass through the analyser. When voltage is applied, the liquid crystals no longer rotate the polarised light as much and less can pass through the analyser. When fully on, the plane polarised light is not rotated at all and none passes through the analyser and we see black.
- A.6.7.13** Voltage is selectively applied to the liquid crystal pixels situated where needed to form the number 9. To prevent light passing, a voltage makes sure the liquid crystal no longer rotates the polarised light and it cannot pass through the analyser and it is black. The mirror at the bottom reflects the ambient light so that the image can be seen.
- A.6.7.14** Red, green and blue filters are used to generate coloured pixels. If these pixels are close together the eye will mix the primary colours to produce any shade needed.
- A.6.10.1** Each plane of light of incident beam can be resolved into a component along the direction of the sheet's polarisation and one perpendicular to it. Only the components parallel to that of the sheet will emerge and the other will not. Hence, in each case emerging light will be of intensity 2.5 W m^{-2} .

A.6.10.2 C

A.6.10.3

Relative angle	Intensity (W m^{-2})
0°	5
90°	0
75°	0.17
60°	0.63
45°	1.25
30°	1.87